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Water Pollution
Control Branch

Wakaw Lake
Water Quality Study
1979-80

November 1985
WPC 83

WAKAW LAKE

WATER QUALITY STUDY

1979-80

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Water Pollution Control Branch
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SUMMARY

Wakaw Lake is a high-use recreational water body located approximately 90 km northeast of Saskatoon and and 0.5 km due east of Wakaw Townsite. Development of summer cottages is prominent along much of the lake's perimeter. Inherent to high public usage of a water system and adjacent shoreline areas are concerns regarding the potential for degraded water quality and increased nutrient loading. A one-year water quality study of Wakaw Lake was conducted by the Water Pollution Control Branch during 1979-80 in order to address these concerns.

The study, consisting of 4 survey periods was designed to document existing lake water quality condition, evaluate current water quality in terms of provincial surface water quality objectives, note seasonal and spatial changes, and to characterize present lake fertility or trophic status.

The aspects of water quality examined during the study included physical and chemical characteristics, bacteria, phytoplankton, aquatic macrophytes and benthos. Sixteen sampling locations were established for study and sample collection was conducted in accordance with standard Water Pollution Control Branch field procedures.

Overall evaluation of chemical and bacteriological parameters indicates that the water quality of Wakaw Lake is satisfactory for contact recreation and for the protection of aquatic life. Indicator bacteria densities were very low during all sampling periods. With exception of August 1979, minimal

temperature and oxygen stratification occurred during ice-free periods, probably due to wind driven mixing. Oxygen saturation was lowest near the lake bottom in August 1979 and February 1980. Seasonal and diurnal fluctuations in concentrations of oxygen and many other chemical parameters is indirectly influenced by algal and aquatic macrophyte metabolism, respiration and decomposition. Conductivity results indicate that Wakaw Lake is moderately saline.

Trophic indicators such as phosphorus, chlorophyll "a", Secchi transparency, and phytoplankton abundance suggest that Wakaw Lake is eutrophic (very productive). The abundance of phytoplankton and submersed plant growth is a natural condition resulting from the shallow lake morphometry and an abundant supply of nutrients. These nutrients enter the lake primarily through surface runoff over adjacent cleared and agricultural lands, and are cycled within the lake during the decomposition of algae and plant material. Nutrient inputs from sewage sources appear to be negligible.

The data obtained in this study provides a useful baseline for monitoring future changes in Wakaw Lake water quality.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Wakaw Lake is located in south central Saskatchewan approximately 90 km northeast of Saskatoon and about 0.5 km due east of Wakaw Townsite (see Figure 1). The lake's scenic location and proximity to large urban centres make it a popular destination for outdoor recreationists. This is particularly true for water based activities such as fishing and boating. Continuing development of summer cottages along much of the lake perimeter also is prominent.

Often inherent with high public usage of a lake system and its surrounding basin area is increased awareness and concern over water quality. Such concerns often include: (1) the potential for increased nutrient loading; (2) increased aquatic macrophyte and algae growth; and (3) increased incidence of partial fish kills. In order to respond to such concerns and to institute sound lake management decisions, comprehensive baseline data regarding limnological status is prerequisite. To help meet this requirement Saskatchewan Environment initiated an intensive water quality study of Wakaw Lake during the summer of 1979.

1.1 Objectives and Scope

The primary objectives of the Wakaw Lake study were:

(a) to document existing lake water quality condition so as to allow identification of future changes;

(b) to evaluate the study results in terms of Saskatchewan surface water quality objectives; and

(c) to describe the trophic characteristics of Wakaw Lake and determine present lake fertility or trophic status.

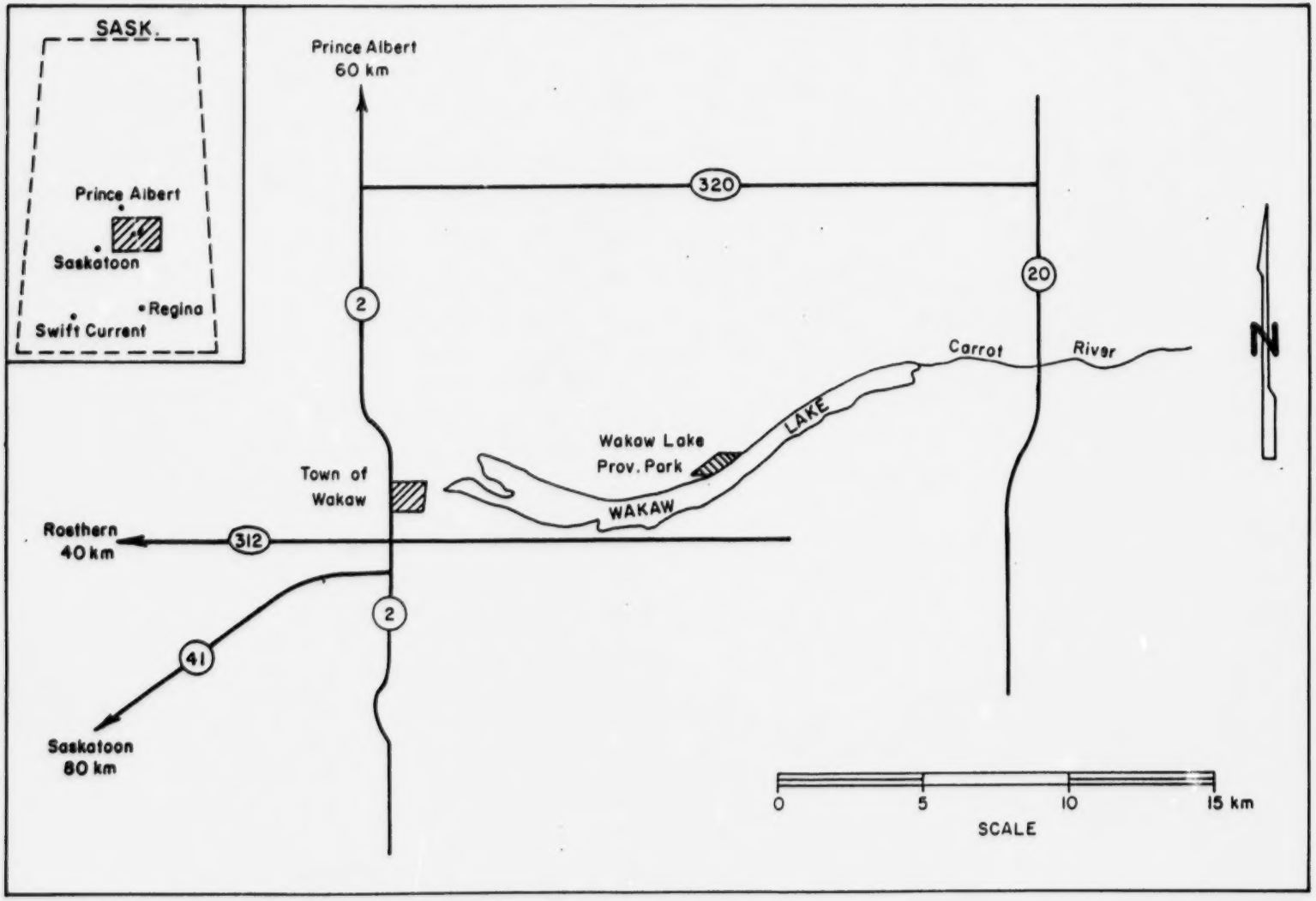


Figure 1: Geographic Location of Wakaw Lake

2. BACKGROUND

2.1 Physical Geography

Wakaw Lake is situated amongst the Boreal Forest and Grasslands region of Canada. The lake basin area is regarded as an Aspen Grove region. Wooded communities of Trembling Aspen, White Birch Balsam and Poplar are intermingled with deciduous shrubs, Upland and Meadow prairie and occasional marshlands (Anon., 1975). Upland prairie is found along the south facing bluffs while Meadow prairie is extensive along the northwestern side of the lake.

Wakaw Lake lies within a well defined channel, once the major outlet of Lake Saskatoon during the recession of the Wisconsin glacier (Edmunds, 1962). The present topography of the surrounding terrain is characterized by gently to moderately rolling hills, occasional valleys, escarpments and isolated hills. The area also is frequented by small intermittent lakes and potholes.

Black soils are dominant in the lake basin. The backshore soils are characteristicly rocky clay, having a high moisture absorption capacity. The shoreline of Wakaw Lake is predominately rocky clay whereas the lake shore interface is a combination of boulders at the waterline and soft clay mixed with rocks under the water resulting in a soft oozy lake bottom (Anon., 1975). There are only three shoreline areas of firm gravel and/or sand. These respective sites are; Sandy Point, Poplar Beach and Domremy Beach.

Wakaw Lake is located within the "Continental" climatic zone. The local climate is classified as a "Dry Subhumid" moisture region (Richards and Fung, 1969). Weather in this region is characterized by warm summers, cold winters and moderate precipitation.

Statistical weather information specifically for Wakaw Lake is not available. However, a general summary of local climate as presented by Anon., 1969a (cited by Anon., 1975) follows. Mean winter temperature is -10°C while mean (24 hr.) summer temperature is approximately 12°C. Annual precipitation averages 35-41 cm, with approximately 60% occurring between May and October. Average annual evaporation ranges from 48 to 56 cm, resulting in an overall moisture deficit. This precipitation - evaporation deficit ultimately contributes to the lake's saline status.

The prevailing winds during the summer months are from the west whereas winter winds generally blow from the northeast.

2.2 Morphometric and Hydrological Characteristics

Wakaw Lake has a mean surface elevation of about 509 metres above sea level. Total surface area of the lake is approximately 1040 hectares. Maximum lake length and width are 17.7 km and 0.8 km respectively. Shoreline length totals 44.4 km excluding that of four small islands located at the lake's southwest end. These islands are quite small with the largest being only 8 ha

(20 acres). Their maximum elevation is less than 3 m above the mean lake level (Anon., 1975).

The lake's maximum depth is 13.9 m, although mean depth approximates 4.7 m. Extensive shallows are located at the northeast and southwest ends (see Figure 2). Overall, at least 50% of the shoreline has a very shallow gradient with only 0.6 m of water at 27 m from shore.

The gross drainage basin area of Wakaw Lake is estimated at 259 km^2, with an effective drainage area of 142 km^2. The lake is fed by several intermittent streams which are active during spring runoff and during prolonged periods of precipitation. Numerous springs are located on the south shore between Poplar Beach and Sandy Point. These springs provide a source of relatively clean water to the lake.

Outflow is provided by the Carrot River which originates at the lake's northeast end. Outflow occurs during the spring runoff and gradually declines as lake inflow decreases and summer evaporation increases. The natural weir at the outflow is recorded as 509.07 metres in elevation (Anon., 1975). Occasionally levels drop below this elevation and outflow ceases.

Water levels during the ice free period (April-October) are usually highest in May and lowest during October. The mean lake

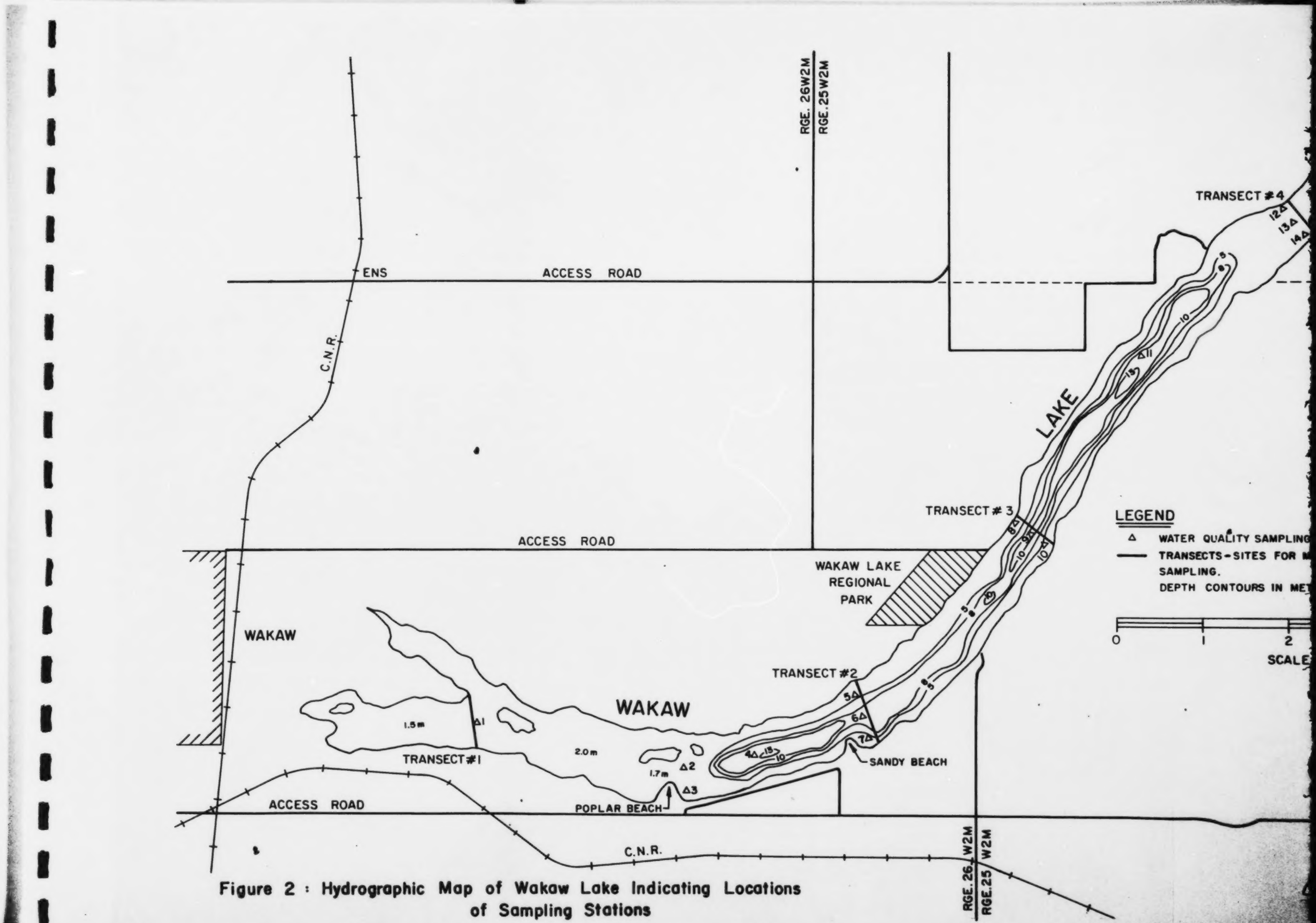
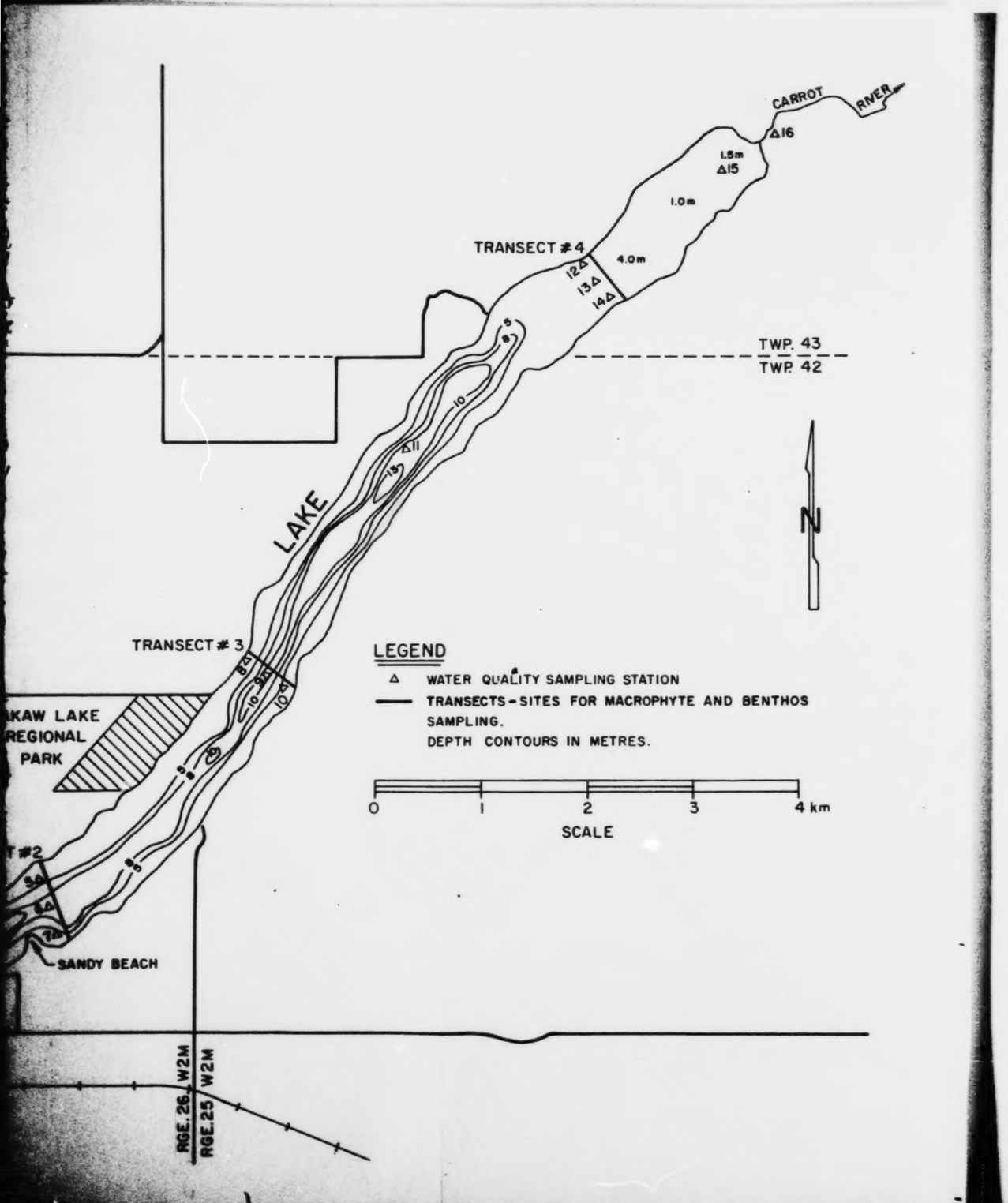


Figure 2 : Hydrographic Map of Wakaw Lake Indicating Locations of Sampling Stations



levels (1966-82) for these months were 509.63 m and 509.23 metres respectively (see Figure 3). This indicates an average annual lake level fluctuation of 0.20 m between the spring runoff and late October period. Seasonal lake levels appear to be dependent on climatic conditions such as amount of spring runoff, precipitation, temperature and evaportranspiration rates. The overall lake level fluctuation during 1979 (a flood year) was 0.44 m. The highest recorded lake level was 510.14 m in 1955. Lake levels recorded from 1966-82 during open water months are summarized in Appendix A, Table A-1.

2.3 Water and Land Use

Of an estimated effective drainage area of 142 km^2, only 21 km^2 lies below the escarpment. Of these 21 km^2, approximately one-half is comprised of the lake basin and the remainder by the valley slopes. The scarp separates the relatively flat cultivated land from the wooded valley sides. This separation provides a natural division between agricultural and recreational activities.

Wakaw Lake is a popular destination for water-oriented recreation. Recreational activities enjoyed at Wakaw Lake include: fishing, swimming, boating and water skiing. Land-related activities include picnicking, walking and hiking.

Recreational use of Wakaw Lake is primarily by residents living within a 120 km radius of the lake, with the majority coming from Saskatoon (Anon., 1975).

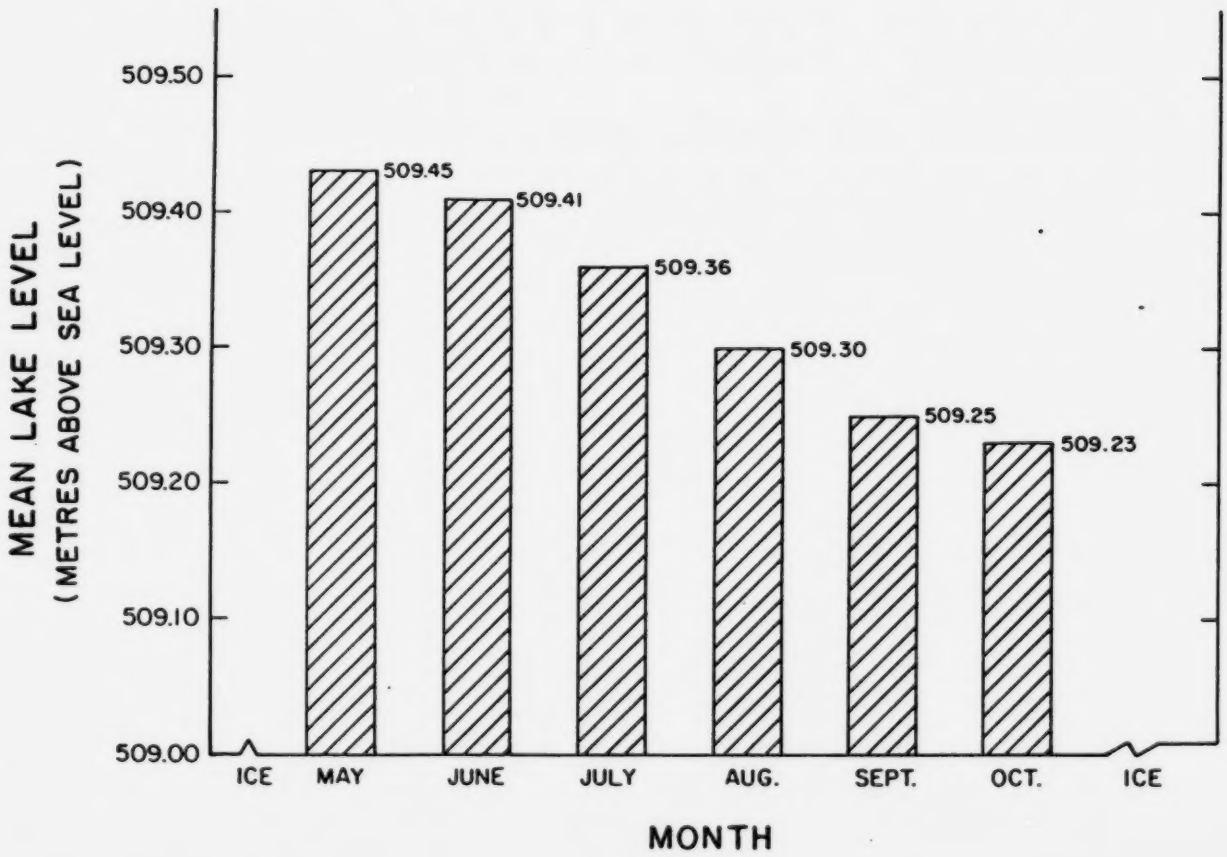


Figure 3 : Mean Lake Levels For Wakaw Lake During Ice-Free Months (1966 – 1982)

Recreational land at Wakaw Lake is comprised primarily of parklands. The park areas consist of a 58 ha (143 acre) regional park on the north central shore (see Figure 2) and 8 ha (20 acres) of public reserves amidst subdivisions.

As of 1975, there were 346 cottages along the lakeshore and an additional 258 empty registered lots available for cottage construction (Anon., 1975).

The land above the escarpment is used primarily for urban and agricultural purposes. The Town of Wakaw (population 1030) covers an area of 2.5 km^2 between Highway 2 and the lake's west end. The remaining land is agricultural, comprised of cultivated cropland, improved pasture, and unimproved range land.

3. STUDY DESIGN

A comprehensive water quality assessment study of Wakaw Lake was initiated by Water Pollution Control Branch staff during August 1979. A total of 16 sites, as designated in Figure 2, were sampled during four distinct sampling periods. These respective sampling dates were as follows: August 20-22/79, October 15-17/79, February 25-27/80, and June 02-04/80. With exception of Station No. 7, near shore sampling sites were located such that water depth was 1.0 to 1.5 m in depth. Deep water sites along sampling transects were located to approximate mid-lake.

Diurnal water quality sampling of Wakaw Lake was conducted during the first 24 hours of the August 20-22, 1979 and June 02-04, 1980 survey periods. During these surveys, single samples were collected approximately every four hours from each station with two of the sample times as close as practical to sunrise and sunset. Beyond the first 24 hours of sampling, a single day-time sample was collected at each site on each of the remaining days. Single water quality samples were collected on each day of the October 1979 and February 1980 surveys. An exception to this sampling strategy occurred in February 1980 where stations No. 4, 9 and 11 were replicate sampled four times at two minute intervals on each of the three sampling dates.

Water quality sampling sites 1-16 inclusive, were sampled during the August and October 1979 survey periods. Only sites 1-15 were sampled in February 1980, and only sites 2-15 were sampled in June 1980. Sites

No. 1 and No. 16 were omitted during these surveys due to difficult access and shallow water.

3.1 Water Quality Parameters

Field analysis conducted at each sampling site included: water transparency by Secchi disk, vertical profiles of oxygen concentration and water temperature, conductivity, and pH. Also, water was collected for algal identification, enumeration and cell volume determination by Branch staff; and for bacteriological assessment and analysis of 20 chemical parameters by the Provincial Laboratories in Regina. Secchi transparency was not recorded during February 1980 due to ice cover.

In addition to vertical oxygen and temperature stratification analysis, a continuous 24 hour taped record of these parameters was obtained at station No. 1 (1 m depth) on August 20-21, 1979. This was achieved using an automated continuous oxygen and temperature recorder.

Bacteriological and chemical parameters analyzed by the Provincial Laboratories included: total coliforms, fecal coliforms, fecal streptococci; total phosphorus, chlorophyll "a", chloride, carbon, nitrogen, alkalinity, iron and manganese. With the exception of total alkalinity, all 20 chemical parameters analyzed were included during each of the four survey periods. Total alkalinity was not analyzed for during the August 1979 and June 1980 surveys.

Details regarding technical methodology employed by staff members during analysis of physical parameters, water collection, and biological sampling are available from Saskatchewan Environment's WPCB procedures manual (Anon., 1984).

3.2 Biota

Phytoplankton samples collected during open water periods were limited to a single sample from each station during the August 1979 and June 1980 surveys. No phytoplankton samples were obtained during October 1979. Phytoplankton samples collected during the February 1980 survey consisted of one sample from each station during each of the three days surveyed. Phytoplankton samples were not collected at station No. 16 during any survey period. Other omissions were, stations No. 11 and 12 during August 1979 and station No. 1 during June 1980.

In all instances, phytoplankton samples were drawn from the composite water quality samples collected at each station for lab analysis. These sub-samples consisted of 50 mLs of lake water preserved with approximately 0.5 mLs of Lugol's solution.

Analysis of the phytoplankton samples involved; identification to the lowest possible taxonomic level (e.g. species, genus or family); cell enumeration (i.e. number of individuals of a particular species per litre of water); and cell volume determinations in order to estimate biomass.

The survey of aquatic macrophyte growth within Wakaw Lake was limited to qualitative documentation of general species composition and distribution, and assessment of general abundance. The above-mentioned documentation was achieved on August 21, 1979 by employing skin diving techniques along the length of four surface transects (see Figure 2).

Benthos were sampled at Wakaw Lake on August 21, 1979. Single sediment samples were obtained from each of stations No. 1 and No. 5-14 (inclusive) using a Eckman dredge. Shortly after collection, the benthic organisms were sorted from the sediments using standard seives. The benthos samples collected from each sediment sample were then preserved separately (according to station) with 37% formaldhyde. These were then submitted in glass vials to the Saskatchewan Research Council for identification and enumeration.

4. RESULTS AND DISCUSSION

4.1 Chemical Evaluation

4.1.1 Dissolved Oxygen and Temperature

Oxygen is a fundamental parameter of aquatic systems, being required by all aerobic metabolizing organisms. Oxygen is moderately soluble in water. The amount of dissolved oxygen (DO) present in a particular water body is dependent on temperature, salinity, turbulence (surface mixing) and atmospheric pressure (decreasing with altitude). Oxygen solubility is negatively correlated with water temperature. An inverse relationship also exists between salinity and DO, whereby increases in salinity result in lower oxygen solubility. This is of significance due to Wakaw Lake's moderately saline status (see Section 4.1.3). The solubility of atmospheric oxygen is inversely proportional to altitude and water temperature. Despite being a physical parameter, temperature has been included in this section due to its close relationship with DO solubility.

The sources of oxygen dissolved in water include photosynthesis by aquatic plants (including algae) during daylight hours, and the atmosphere. The latter source involves diffusion at the air-water interface, often enhanced by surface turbulence.

The inputs of oxygen into a lake system are continually offset by consumptive metabolism. This includes aerobic decomposition of dead organisms such as aquatic plants, and the respiration of plants and algae during periods of darkness. These processes can reduce dissolved oxygen levels and contribute to diurnal and seasonal fluctuations.

As a lake becomes more eutrophic, and increasing quantities of plants and animals respire and decay, the balance shifts toward consumption. This is particularly true of the lake bottom where dead organisms accumulate. Depletion of oxygen at the substrate indirectly promotes further eutrophication. As the quantity of oxygen near the bottom decreases, the chemistry of the mud and water changes. Phosphorus normally bound to the mud when oxygen is present moves up into the water column promoting the growth of algae.

A summary of seasonal mean diurnal temperature and dissolved oxygen depth profile data collected at the deep water station (Station No. 4) is presented in Figure 4 and Appendix B(Table B-1). Dissolved oxygen in the Figure 4 profiles is expressed in terms of per cent saturation. This method of expression is desirable since it provides information regarding the degree of saturation of the water with respect to water temperature. Variations from

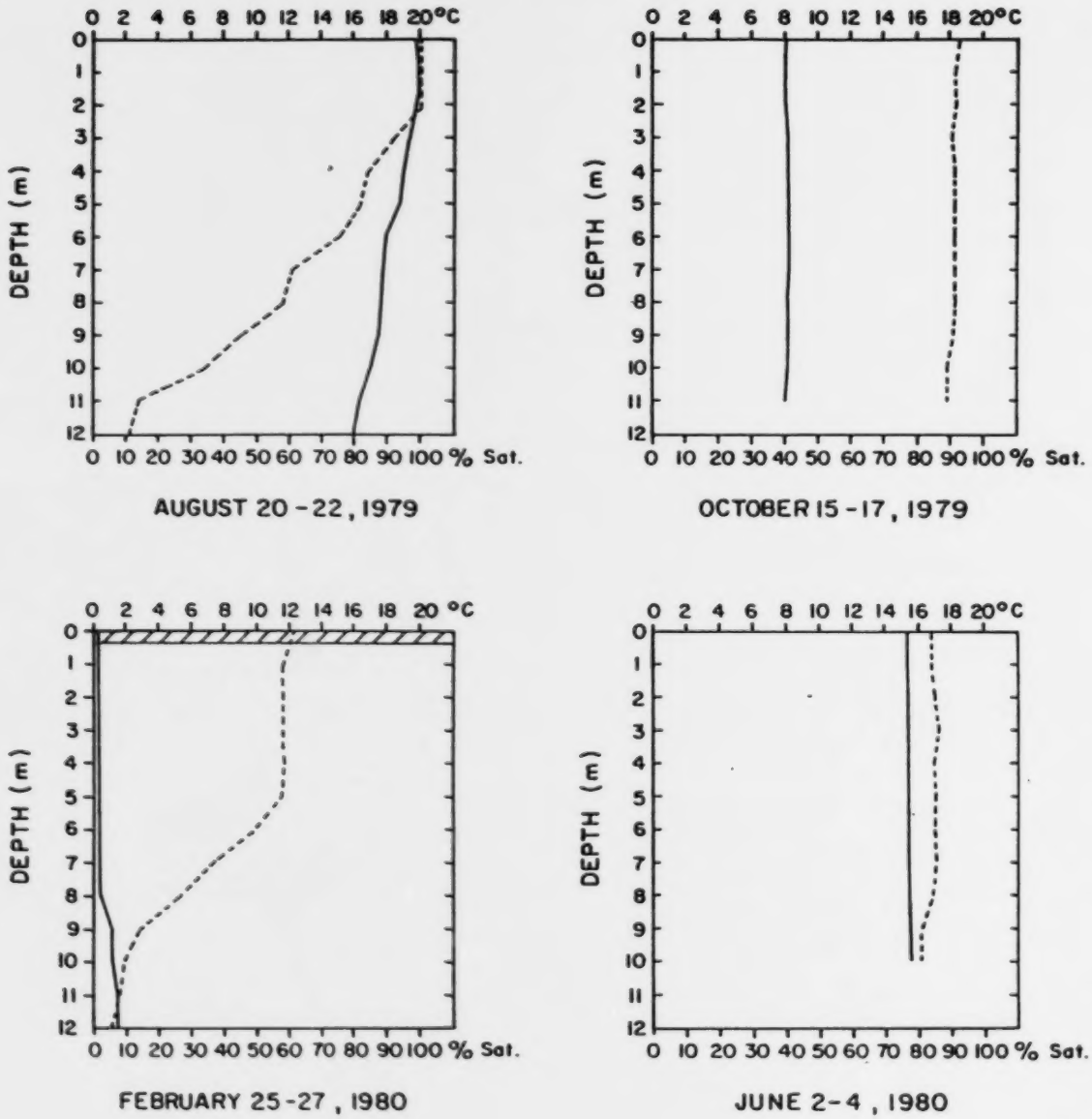


Figure 4 : Mean Temperature (°C) and Dissolved Oxygen (% Saturation) Profiles For Wakaw Lake, Station # 4 (Deep Water Station), August 1979 – June 1980

expected saturation values for any particular water temperature indicate that some substance or process is utilizing or producing oxygen at a rate exceeding its diffusion from the atmosphere.

Figure 4 indicates that diminutive temperature stratification occurred during August, 1979. No temperature stratification was observed during June, 1980 and only minimal stratification during the October, 1979 survey period. The general absence of definitive temperature stratification during ice-free periods suggests that the lake's exposure to wind causes considerable mixing of the water column. Mendis (1956) also attributed minimal stratification during ice-free periods to wind-driven mixing. Such mixing also would account for the relatively high and consistent DO saturation values observed in October 1979 and June 1980 (see Figure 4).

Although wind driven mixing of the water column during August 1979 was evident, mean DO saturation decreased steadily with depth. Mean DO saturation at the lake bottom (12 m) was only 11% which approaches anoxic conditions. It should be noted, however, that several determinations during the August 1979 survey period indicated zero per cent DO saturation at the 12 metre depth. Saturation rates below 20% are stressful to fish and fish generally avoid DO

levels below 3.0 mg/L. The apparent net consumptive trend below the 6.0 metre depth is likely the result of oxidative processes (e.g. decomposition of algae). The clinograde-like oxygen profile displayed in August 1979 is characteristic of eutrophic lakes during periods of summer stratification.

During the February 1980 survey period when ice was present, a more well defined temperature stratification occurred (see Figure 4). Mean temperature began to increase progressively beyond the eight metre depth producing a slight orthograde curve. Mean temperature was highest (1.2°C) at the lake bottom. Oxygen saturation in contrast declined with depth producing a clinograde curve. The mean temperature and oxygen saturation patterns displayed during February 1980 are characteristic of winter stratified eutrophic lakes having ice cover.

Although mean DO saturation at 12 metres during February 1980 was very low (5%), totally anoxic conditions (zero per cent) such as some observed during August 1979 did not occur. However, mean oxygen saturation below the 8.5 metre depth was less than that required by fish (20%) (see Figure 4). The overall lower oxygen levels observed in February 1980 are probably related to the presence of ice cover. Ice and snow cover essentially prevents atmospheric

exchange of oxygen, limits photosynthetic contributions and prevents wind driven mixing of the water column. This is further aggravated by consumptive processes such as decomposition of organic material at the lake's bottom.

Figure 5 illustrates the variations in DO concentration which occurred in Wakaw Lake (Station No. 1) over a 24 hour period during the summer of 1979. Temperature was included in Figure 5 to demonstrate the close relationship observed between the two parameters. Dissolved oxygen concentration and temperature both peaked at 7:00 p.m. of August 20, 1979 and were lowest at 7:00 a.m. of August 21, 1979. Normally, temperature and DO are inversely correlated, with oxygen solubility increasing with lower water temperatures.

Despite lower water temperatures at night, oxygen saturation declined during periods of darkness. The rapid decline of DO levels which occurred during hours of darkness can likely be attributed to the shift of algal and plant photosynthesis to consumptive respiration. During periods of darkness, algae begin to respire utilizing oxygen from the surrounding water. The rapid renewal of DO during the late morning hours of August 21, 1979 indicates active phytosynthesis by phytoplankton.

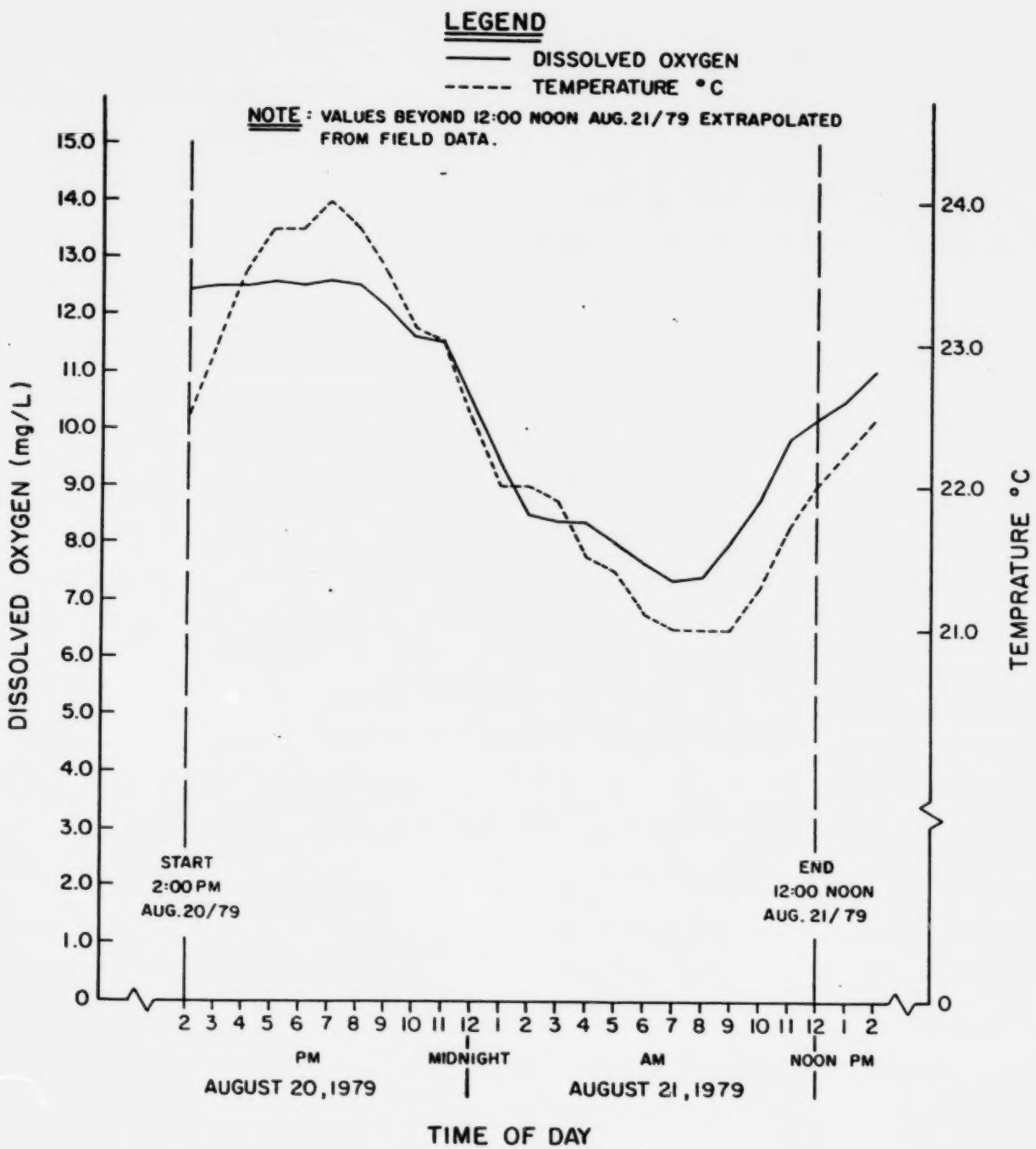


Figure 5 : Diurnal Dissolved Oxygen Concentration (mg/L) and Temperature at Wakaw Lake (Stn. #1 at 1m Depth), August 20 - 21, 1979 (as Indicated by Continuous DO Recorder)

Although serious reductions in DO resulting from night-time algal respiration were not observed, large algae blooms present during calm nights can result in oxygen depletion and fish kills. Occasional localized fish kills have been reported at Wakaw Lake in the past. The most recent was in July of 1985.

4.1.2 Total Organic Carbon

Total organic carbon in fresh waters consists almost entirely of dissolved organic carbon and dead particulate carbon (Wetzel, 1975). The ratio of dissolved to particulate forms approximates 10 to 1. Most of the organic carbon in water is composed of humic substances and partly degraded plant and animal material.

Carbon in aquatic ecosystems is continually cycled between the organic and inorganic state. The source of all organic carbon is carbon dioxide (CO_2). Aquatic plant forms (e.g. algae) utilize CO_2 from the water during photosynthesis converting it into carbohydrates. As the plant material dies, organic carbon in the dissolved and particulate form are released into the water. The amounts of organic components vary with lake discharge and especially with the growth cycles of vegetation. Other sources of organic carbon in aquatic systems include surface runoff from forested and agricultural lands, detrital input such as leaves, and municipal waste discharges.

Total organic carbon (TOC) is a concern in water quality studies since the decomposition of carbon compounds removes oxygen from the water. Excessive amounts of organic carbon can reduce dissolved oxygen to levels below that required by respiring aquatic organisms such as invertebrates or fish.

Mean seasonal TOC data for Wakaw Lake is summarized in Appendix B (Table B-2). Mean TOC concentrations for the months of August 1979, October 1979, February 1980 and June 1980 were; 14, 17, 15 and 18 mg/L respectively. These mean concentrations are well within the environmental range of 1 to 30 mg/L reported for natural surface waters by McNeely et al., (1979). The slightly higher TOC concentrations observed during October 1979 as compared to those of August 1979 was probably the result of increased vegetative degradation. In the fall, submergent weed beds characteristically scenesce and decompose. Significant spatial (i.e. between stations) trends in TOC data were not apparent.

4.1.3 Salinity and Total Dissolved Solids

Lake water contains a multitude of dissolved substances. If water is filtered to remove living organisms and other particles, and then allowed to evaporate, the residue is called Total Dissolved Solids (TDS). The ions (e.g.

sodium) which compose most of this residue can be measured individually. When added together, they give a value of total salinity. The total salinity of inland waters usually is dominated completely by four major cations; calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), and, the major anions; carbonate (CO_3), sulfate (SO_4), and chlorides (Cl) (Wetzel, 1975).

Salinity in lakes is controlled by the types of rock or soil in the watershed and by the amount of evaporation relative to precipitation. When evaporative losses from a lake exceed precipitation, salinity of the water body increases since "residue" material remains behind thus concentrating the TDS present. This is usually an additive process with the outcome being increased TDS or salinity.

The primary water quality concern regarding TDS most often involves the taste and palatability of water rather than detrimental health effects to man and aquatic biota. High TDS concentrations may limit the suitability of water as a drinking or irrigational source. Total dissolved solids concentration, as estimated by specific conductivity also is useful as a general indicator of lake fertility. In addition, oxygen solubility decreases with increased TDS or salinity.

4.1.3.1 Conductivity

Conductivity is a measure of a water's ability to conduct an electrical current. The resistance of water to electrical current is reduced with increased content of ionized salts. As such, pure water has a higher resistance to electrical flow than does saline water. On this basis, conductivity can provide a useful estimate of the TDS concentration or salinity of water.

A summary of seasonal mean conductivity data for Wakaw Lake is presented in Appendix B (Table B-3). Mean seasonal conductivity was highest (3350 us/cm) in August 1979 and lowest (2960 us/cm) during October 1979. Mean seasonal conductivity during February 1980 and June 1980 were 3020 us/cm and 3200 us/cm respectively. No significant spatial trends with regards to sampling location were noted. The higher conductivity values noted during August 1979 and June 1980 may be associated with the active aquatic plant growth and photsynthesis which characteristically occur during these periods. The release of carbon dioxide (CO_2) as a by-product of photosynthesis by abundant plant and algae growth can alter pH and increase the

alkalinity of the surrounding waters through the formation of carbonate. A nearly 1:1 relationship ($r = 0.997$; Otsuki and Wetzel, 1976) exists between conductivity and changes in calcium and carbonate concentrations in hard water lakes (Wetzel, 1975). Subsequently, increases in alkalinity can increase conductivity. Also, high evaporation, minimal outflow, and lower lake levels likely contributed to the higher conductivity readings recorded during August 1979.

A firm water quality objective for conductivity has not been established. However, an objective for TDS concentration of 1500 mg/L or less has been designated for drinking water by Saskatchewan Environment (Anon., 1980). Since specific conductivity (at 20°C) is in general terms, often equated with TDS concentration, Wakaw Lake water can be said to exceed the TDS objectives for drinking water. Hedlin Menzies and Associates (Anon., 1975) reported a summer TDS of 3375 ppm in 1974.

Based on a classification of TDS and salinity relationships presented by McNeely et al., (1979), Wakaw Lake typifies a moderately saline lake.

Timms (1985; unpublished) found the lake to be moderately saline with conductivity averaging 3000 us/cm at 20°C. The relatively high conductivity and TDS values characteristic to Wakaw Lake are probably a result of the cumulative effects of evaporation and ground water input.

4.1.3.2 Chlorides

Unlike in seawater, chloride generally is not a dominant ion in open lake systems. Concentrations of this inorganic anion can, however, vary considerably between different natural surface waters. Variation is due primarily to climatic conditions, with waters in semi-arid regions generally having higher chloride concentration than those of humid regions. Common sources of chloride include the weathering and leaching of sedimentary rocks and soils, and the salting of roads in winter.

Although chloride is influential in general osmotic salinity balance and ion exchange in aquatic organisms, metabolic utilization by such organisms does not cause significant variations in its spatial or seasonal distribution within a lake (Wetzel, 1975). For this reason, significant

spatial variations in chloride concentration within a lake system are often considered indicative of external pollutants such as industrial discharges or domestic sewage.

Appendix B (Table B-4) summarizes the seasonal mean chloride concentrations recorded during the Wakaw Lake study. Although variations in mean chloride concentration was minimal between sampling sites, a more well defined seasonal variation was evident. Seasonal mean chloride concentration was lowest (54 mg/L) during the June 1980 survey and highest (63 mg/L) during February 1980. Concentrations during August and October of 1979 were 59 mg/L and 61 mg/L respectively. In contrast, the high mean February concentrations were probably due to the combined effects of; reduced flushing rates; concentration by evaporation during the summer and fall months; formation of ice cover; and the increased significance of ground water.

Overall, the observed seasonal mean chloride concentrations were characteristic of a moderately saline lake. The chloride data obtained indicates that pollution from point sources and seepage of domestic sewage was insignificant.

4.1.4 pH and Alkalinity

The pH of lake water refers to the concentration of hydrogen ions in solution. The pH scale runs from zero (extremely acidic) to 14.0 (extremely alkaline). A pH of 7.0 is considered neutral, being neither acidic nor alkaline. A change of one pH unit represents a tenfold change in hydrogen ion concentration (e.g. a pH of 6.0 has ten times the hydrogen ions of pH 7.0). The pH of most natural waters range from 4.0 to 9.0 depending on the amount of bicarbonate-carbonate present (i.e. alkalinity).

Alkalinity refers to the capacity of water to neutralize an acid, and is a measure of the alkaline material present in the water. Although the alkalinity of natural waters is generally the result of bicarbonates, it is usually expressed in terms of calcium carbonate ($CaCO_3$) concentration.

Mean seasonal pH and total alkalinity results for Wakaw Lake are summarized in Appendix B (Tables B-5 and B-6 respectively). The pH during all survey periods was slightly on the alkaline side of neutrality. Mean pH values were highest (8.6) in August 1979, followed by 8.4 in June 1980. Alkalinity concentrations during these respective survey periods were not recorded. Seasonal mean pH was lowest (7.7) during February 1980. Of interest was

the fact that mean total alkalinity concentration for this period (197 mg $CaCO_3$/L) was higher than that of October 1979 (159 mg/L). Generally, an increase in alkalinity as observed from October 1979 to February 1980 would be reflected by an increased (more basic) pH. It is probable therefore that the increased mean total alkalinity noted in February 1980 was accompanied by a higher proportionate increase in acidic components. Ice cover, reduced photosynthesis and low water temperature during winter months combine to retain a greater concentration of carbon dioxide and subsequent carbonic acid. This could have contributed to the lower mean pH values observed in February 1980. Additionally, acidity associated with the decomposition by-products of plant decay during winter months also may have served to lower the pH observed during February 1980. The increase in mean total alkalinity noted from October 1979 to February 1980 was likely a result of concentration by ice formation and the return of precipitated $CaCO_3$ (marl) on aquatic plant surfaces back into solution.

Overall, the pH values recorded for Wakaw Lake lie within the upper limits of the provincial surface water quality objective range of 6.5 to 8.5 units established by Saskatchewan Environment in 1975. The observed values also are quite consistent with historical levels. Mendis (1956) found that mean pH in Wakaw Lake ranged from 8.0 to 8.4 units.

4.1.5 Iron and Manganese

Iron and manganese are discussed together in this section due to their similarities in chemical reactivity and impacts.

Iron may be present in solution in both the ferrous and ferric state. The mobile ferrous form predominates under anaerobic or poorly oxygenated conditions but readily oxidizes to the less mobile ferric state in well aerated waters. Under such oxidizing conditions, an iron precipitate is formed, which when abundant can cause nuisance impacts due to staining of plumbing fixtures and encrustation of pipes. Excessive concentrations (above 0.3 mg/L) also may promote bacterial activity in pipes and service mains. The solubility of iron increases with decreasing pH.

Manganese is considerably more soluble than iron but otherwise is similar in its chemical behaviour. As with iron, manganese is precipitated from solution by an oxidizing environment and diffuses readily from the sediments into the anaerobic hypolimnion of productive lakes when pH is low. Due to these similarities, manganese and iron are commonly found in association, particularly within lake sediments. Manganese concentrations above 0.2 mg/L can render water unpalatable. An objective of less

than 0.01 mg/L has been recommended for domestic sources by the Department of National Health and Welfare (Anon., 1969b) in order to minimize dark brown or black staining on fabrics and porcelain. The provincial objective for manganese is 0.05 mg/L (Anon., 1983).

Both iron and manganese are essential micronutrients of fresh water plants and animals. Also, these elements can under certain conditions of restricted availability be limiting to photosynthetic productivity.

Mean seasonal iron and manganese concentration for Wakaw Lake is summarized in Figure 6 and in Appendix B (Tables B-7 and B-8 respectively). Mean iron concentration was highest (0.3 mg/L) during both the August 1979 and February 1980 survey periods, (see Figure 6). These maximum mean iron concentrations equalled the upper limit of 0.3 mg/L established by Saskatchewan Environment in 1975 as a surface water quality objective.

Mean manganese concentrations ranged from a low of 0.02 mg/L during October 1979 and June 1980 to a high of 0.21 mg/L in February 1980. Mean manganese concentration during August 1979 was 0.06 mg/L. Mean concentrations of this element during the August 1979 and June 1980 survey periods exceeded the provincial objective of 0.05 mg/L.

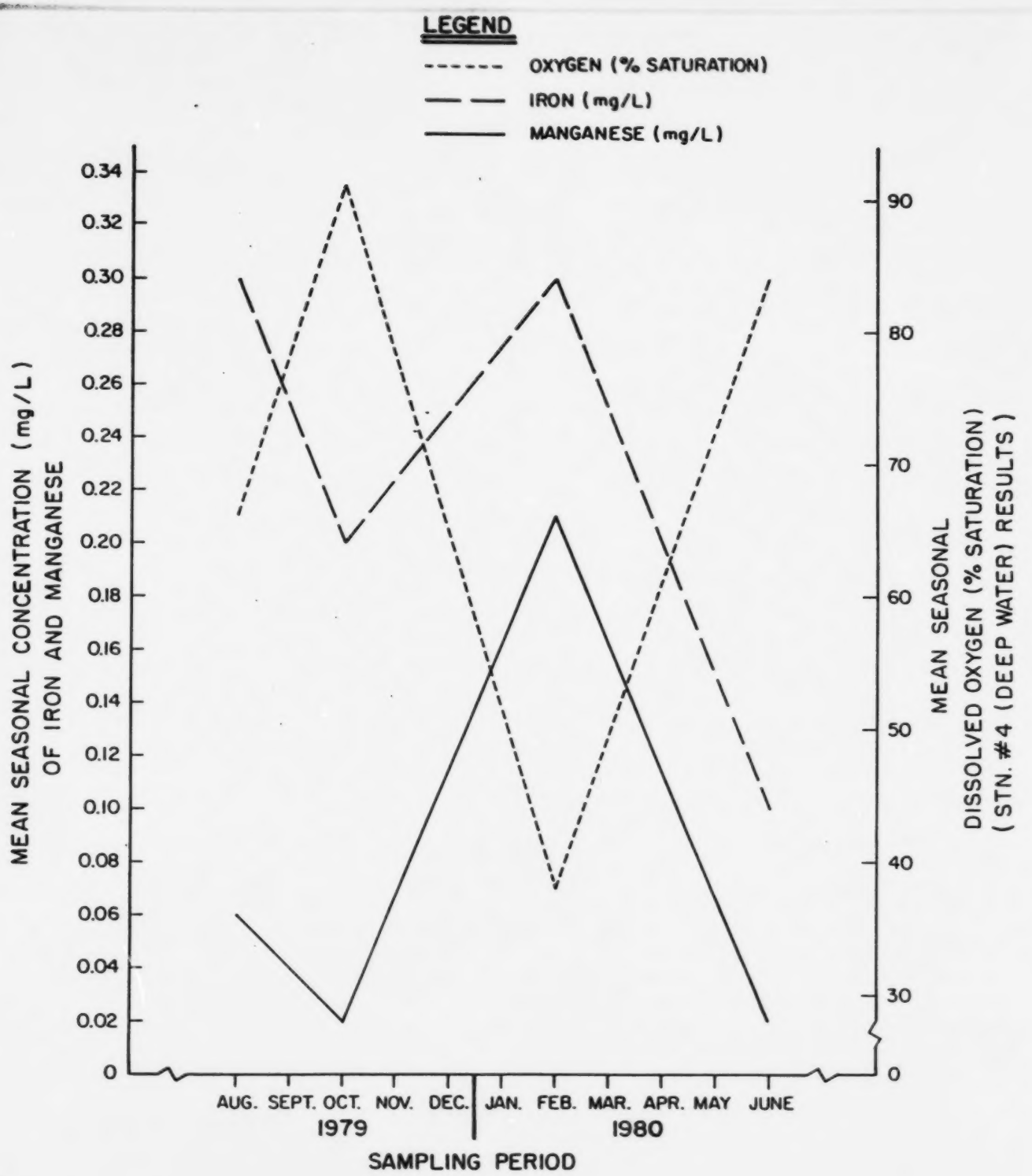


Figure 6 : Summary of Mean Seasonal Iron and Manganese Concentration (mg/L) as Related to Oxygen Saturation in Wakaw Lake , August 1979 – June 1980

Although mean seasonal iron concentrations were considerably higher than that of manganese, overall seasonal trends were very similar (see Figure 6). Figure 6 also demonstrates the inverse relationship which exists between oxygen saturation (oxygenation) of water and the concentration of iron and manganese in solution. The high mean concentrations of iron and manganese observed during February 1980 appear to be directly related to low oxygen saturation levels recorded during this survey period. Conversely, periods of high oxygen saturation, (oxidizing conditions) such as observed during October 1979 and June 1980 were characterized by low mean iron and manganese concentrations.

4.2 Bacteriological Evaluation

Bacteria along with viruses and fungi are present in almost all natural waters. In most instances, these organisms are non-pathogenic. A great number of water-borne and water-associated communicable diseases (e.g. dysentery, gastroenteritis, hepatitis) are caused by pathogenic bacteria and viruses. Humans may contract such diseases by direct exposure to contaminated waters through drinking or swimming. Rosenburg et al. (1976; cited by Levin et al., 1980) reported a swimming associated outbreak of shigellosis[1] at a park beach on the

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1 A form of dysentery caused by aerobic bacterium of the genus Shigella.

Mississippi River. A significant correlation was shown between swimming and occurrence of illness in individuals at the park. In view of such incidents, the general abundance of bacteria in water is a basic water quality concern.

The microbial safety of water is estimated indirectly by the presence and relative abundance of intestinal bacteria. The presence of such bacteria in waters also is indicative of pollution by enteric wastes (i.e. sewage). The most commonly used bacterial indicators are coliforms and fecal streptococci.

Recreational and domestic source waters should obviously be sufficiently free of pathogenic bacteria so as not to pose health hazards through infections. Since non-recreational use of Wakaw Lake water is limited, bacteriological water quality data obtained during this survey is discussed in terms of provincial objectives for direct contact recreation.

4.2.1 Coliform Bacteria

Coliform bacteria have long been used as "indicators" of fecal contamination in waters. These bacteria, however, are associated with both the feces of warm-blooded animals and with soil. Therefore, a quantitative relationship between total coliforms and enteric wastes in surface waters does not exist (Dutka, 1973). Qualitative interpretation of total coliform data is more appropriate.

In Saskatchewan, objectives for total coliform densities in recreational waters are as follows: The geometric mean of not less than five samples taken over not more than a 30 day period should not exceed 1000 organisms (orgs) per 100 ml nor exceed 2400 orgs/100 ml in any one sample. Since less than five samples were taken at each sampling station during several survey periods, means are expressed in the standard form, slightly overestimating the geometric mean.

Appendix C (Table C-1) summarizes the mean total coliform densities observed during the Wakaw Lake study. Mean values ranged from a high of 975 orgs/100 ml during the August 1979 survey to only <2 orgs/100 ml in June 1980. Seasonal mean values (all stations combined) ranged from 3 orgs/100 ml in June 1980 to 490 orgs/100 ml in August 1979. Seasonal means for October 1979 and February 1980 were 182 and 57 orgs/100 ml respectively. All mean seasonal total coliform values (see Table C-1) were below the upper limit objective of 1000 orgs/100 ml established for direct contact recreational waters. However, mean values at sampling stations 3 and 16 (975 and 913 orgs/100 ml respectively) did closely approach this upper limit objective. Only 2 (suspected errant) of the 229 analyses performed for total coliforms exceeded the limit of 2400 orgs/100 ml established for individual samples.

The use of fecal coliform bacteria as an indicator of sanitary pollution has greater significance than does the use of total coliform bacteria. This results from the fact that fecal coliforms, like enteric pathogens, live or originate from the intestinal tract of warm-blooded animals (Geldreich, 1966).

Table C-2 in Appendix C provides a summary of mean seasonal fecal coliform densities recorded during the Wakaw Lake study. As with total coliform density, seasonal mean fecal coliform densities were highest (14 orgs/100 ml) in August 1979 and lowest (<2 orgs/100 ml) in June 1980. Mean fecal coliform values for individual sampling stations ranged from a low of <1 org/100 ml during October 1979 to 70 orgs/100 ml (Station No. 16) in August 1979. Seasonal means for the months of October 1979 and February 1980 were 4 and 2 orgs/100 ml respectively. All mean density values recorded were well below the upper limit objective of 200 fecal coliforms per 100 mls which has been established for direct contact recreational waters in Saskatchewan. Although very low, the fecal coliform densities noted during all survey periods indicate the presence of fecal input. This could originate from either the seepage of human sewage or perhaps livestock or wildlife defecating near or in the water.

The low seasonal mean total coliform and fecal coliform densities recorded in June 1980 may be a result of spring runoff and the associated higher flushing rates (i.e. water replacement) in the lake. The higher mean total coliform and fecal coliform densities noted in August 1979, as compared to other survey periods, may be due to the general increase in public use of the lake and adjacent shoreline areas during this peak summer recreation month. Also, increased watering or activity of wildlife near the lake's edge generally occurs in the summer. This, combined with warmer water temperatures may have contributed to the higher coliform densities observed in August 1979. No spatial trends regarding coliform densities were noted.

4.2.2 Fecal Streptococci

Fecal streptococci are generally more resistant to purification processes than are the coliform group. For this reason, streptococci may be the only indication of fecal pollution at locations distance from the source and where fecal coliforms are no longer present. Fecal streptococci also can provide more information about fecal pollution sources since certain streptococci are host specific (e.g. livestock, wildlife).

Mean fecal streptococci densities for Wakaw Lake are summarized in Appendix C (Table C-3). Mean streptococci

densities ranged from <1 org/100 ml in October 1979 to 187 orgs/100 ml (Station No. 16) during August 1979. Seasonal mean fecal streptococci density also was highest in August (21 orgs/100 ml) and lowest (2 orgs/100 ml) during October 1979. Overall, fecal streptococci densities were quite low indicating minimal pollution from human, livestock and/or wildlife sources. As with coliforms data, no significant spatial trends were evident.

4.3 Trophic Characteristics

The word "trophic" literally means nourishment or fertility. Lakes are generally categorized by terms which relate to degree of fertility, or trophic state. Oligotrophic is the trophic classification for lakes having low productivity, thus a low trophic state. Levels of nutrients such as phosphorus and nitrogen are low, plant growth is sparse, and water clarity is high. On the opposite end of the trophic scale are eutrophic lakes. These lakes are nutrient rich and are characterized by the abundance of aquatic macrophytes, algae and benthic organisms. Mesotrophic lakes are those with intermediate fertility and often combine the best features of the other two. The highest trophic status is hypertrophic. These lakes are extremely nutrient rich and very productive.

The water quality parameters most commonly used as indicators of a lake's trophic status are: levels of the nutrients, phosphorus and nitrogen, chlorophyll concentrations, and water transparency. The relative magnitude and subsequent significance of these parameters is discussed in terms of Wakaw Lake's trophic status.

4.3.1 Phosphorus

Phosphorus in water is present in several soluble and particulate forms (organic and inorganic), together referred to as total phosphorus. The productivity of most lakes is related directly to the amount of total phosphorus (TP) present. Phosphorus is a biologically active element and therfore cycles through many states in the aquatic ecosystem. Concentration in any one state depends on the degree of metabolic synthesis or decomposition occurring in the system.

Phosphorus is a growth limiting nutrient in aquatic plants and is considered by Lind (1979) to be the element most likely to cause a stimulation in plant production. A large phosphorus supply usually results in a higher rate of productivity or trophic state. Inversely, low phosphorus supply is characteristic of waters having a low trophic state (e.g. oligotrophic). Consequently, phosphorus concentration is often implicated as a major factor in the

eutrophication[1] of lakes (Carlson, 1977; Rast and Lee, 1978).

Natural eutrophication of lakes is commonly referred to as aging. This process results from the gradual but steady increase in nutrient supply. The aging of lakes also is related to depth. Through natural succession, lake basins gradually fill with silt and sediments. As a lake basin continues to fill, over long periods of time, volume decreases and the resulting shallowness speeds the cycling of available nutrients such as phosphorus. This in turn further increases plant production. Characteristic of many Saskatchewan lakes, Wakaw Lake is quite shallow and exhibits moderately advanced stages of aging.

A more serious problem is "cultural" eutrophication defined by Hasler (1969). Cultural eutrophication is accelerated nutrification (e.g. phosphorus) resulting from external sources such as sewage, industry, drainage over agricultural lands, and recreation use of water.

In the absence of industry and large urban centres, surface runoff is generally the main external source of phosphorus loading. Based on studies from all over North America,

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1 Eutrophication is a multifaceted term generally associated with increased nutrient concentration and plant growth within an aquatic system (Wetzel, 1975).

theoretical phosphorus supply from surface runoff over agricultural/cleared land averages five times that of forested land (Rast and Lee, 1978). Phosphorus loading from runoff over urban/cottage areas averages 10 times that of forested lands. Agricultural and cottage development within Wakaw Lake drainage basin is quite high (see section 2.3). As such, moderately high total phosphorus levels within Wakaw Lake are expected.

Mean seasonal total phosphorus (TP) values for the Wakaw Lake study are summarized in Appendix D (Table D-1). Mean TP ranged from 0.03 mg/L to 0.07 mg/L. Both of these extremes were noted in February 1980. Seasonal means (all stations combined) were all quite similar. August and October 1979 seasonal means were 0.04 mg/L while February and June 1980 values were slightly higher at 0.05 mg/L. The Saskatchewan surface water quality objective for phosphorus (as P) is 0.05 mg/L (Anon., 1983).

The slightly higher mean TP values observed in February and June 1980 may have resulted from: the release of phosphorus during decay of vegetation; upward migration from the sediments due to anaerobic conditions at the lake bottom (February); and, increased input through surface runoff over adjacent agricultural lands during spring. Also, the utilization of phosphorus by abundant macrophytic and phytoplankton growth during the summer months probably

contributed to reduced phosphorus levels in the water column during August 1979.

Carlson (1977) developed a numerical index (0-100) which categorizes the trophic state of a lake on the basis of algal production. Mean total phosphorus is translated into a Trophic State Index (TSI), with higher values indicating a higher degree of eutrophication. Trophic State Index values also can be derived on the basis of mean chlorophyll "a" concentration and secchi depth. Rast and Lee (1978) believe a TSI of 40 to be the approximate boundary between eutrophic and oligotrophic. Therefore, a lake having a TSI near that number (40) would be considered mesotrophic. The annual mean phosphorus recorded in 1979-80 (45 mg/m^3) translates into a TSI value of 59. Trophic State Index numbers for chlorophyll "a" and secchi depth were 50 and 52 respectively (see Sections 4.3.3 and 4.3.4). All three values infer that the state of Wakaw Lake is lower range eutrophic. Note however, that the TSI values derived may be low estimates due to the presence of prolific macrophyte (weed) growth within Wakaw Lake (see Section 4.4.2).

4.3.2 Nitrogen

Nitrogen is occasionally limiting to plant production and is probably only second to phosphorus in this role for most aquatic ecosystems. Nitrogen is present in aquatic

ecosystems in several important forms. In water, the forms of common analytical interest include: organic nitrogen (dissolved and particulate); ammonia (the most reduced form) which is the product of organic decomposition; and nitrate and nitrite, which are oxidized forms resulting from the bacterial oxidation of ammonia.

General sources of nitrogen in water include: decomposing plant and animal material; surface runoff over fertile agricultural land; municipal and industrial waste discharge; nitrogen fixation by blue-green algae and bacteria; ground water infiltration; and precipitation or air borne deposition. The water quality objective for total nitrogen (total organic and inorganic) in Saskatchewan surface waters has been established as 1.0 mg/L (Anon., 1983). It is recognized, however, that naturally occurring levels in many surface waters in southern Saskatchewan exceed this level.

Total kjeldahl nitrogen (TKN) which includes total organic nitrogen and ammonia is commonly determined to measure the major quantity of nitrogen present in water. High levels of TKN in a water body is often indicative of an abundance of nutrients and therefore provides inference of trophic status. Seasonal mean total kjeldahl nitrogen (TKN) results for each sampling station is summarized in

Appendix D, (Table D-2). Seasonal mean TKN values ranged from 1.32 mg/L during the August and October, 1979, to 2.21 mg/L during the February, 1980 survey (see Figure 7a). The annual (overall) mean TKN concentration was 1.50 mg/L. This level exceeds the objective of 1.0 mg/L for total nitrogen set for Saskatchewan surface waters and is characteristic of concentrations found in eutrophic waters.

Seasonal mean ammonia nitrogen (NH_3-N) concentrations ranged from 0.02 mg/L during October, 1979 to 0.40 mg/L in February, 1980 (see Figure 7b and Appendix D, Table D-3). Mean NH_3-N concentration during August, 1979 and June, 1980 were 0.08 mg/L and 0.03 mg/L respectively. The elevated NH_3-N concentrations observed during February, 1980 were likely a result of:

1. the decomposition of large quantities of perennial aquatic macrophyte biomass;
2. reduced activity by nitrifying bacteria which convert NH_3-N to nitrate (NO_3-N) and nitrite (NO_2-N);
3. reduced NH_3-N uptake by bacteria and algae for nutrient requirements;
4. decreased loss of NH_3-N to the atmosphere due to ice cover; and
5. increased microbial reduction of NO_3 + NO_2-N under anaerobic conditions - anaerobic decomposition at lake bottoms may result due to oxygen depletion by aerobic decomposition of large quantities of plant biomass.

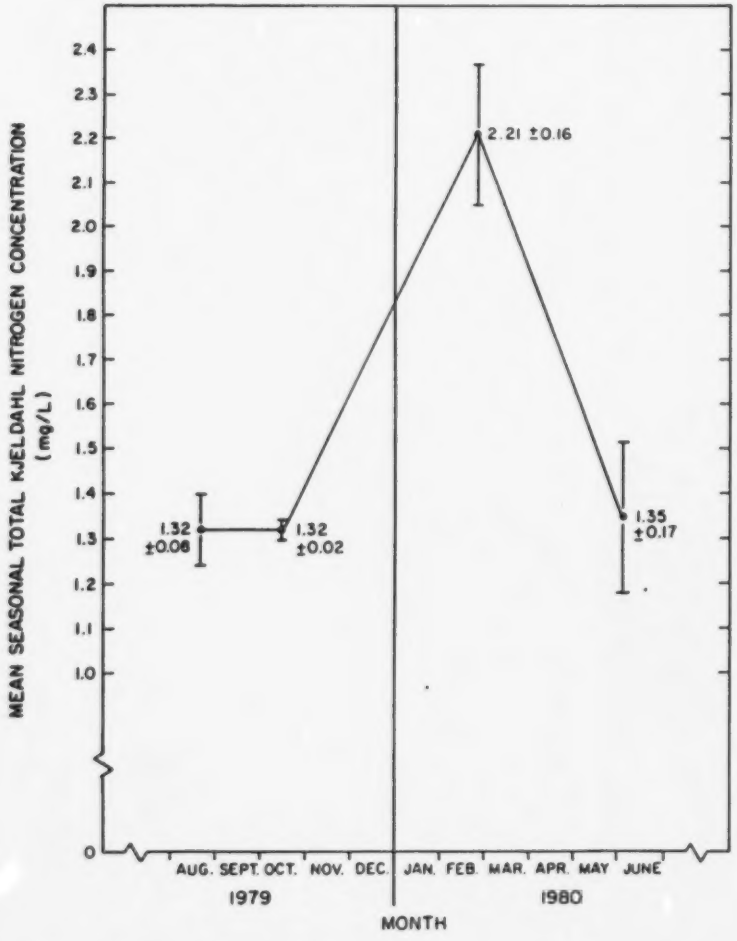

Figure 7a : Mean Seasonal Total Kjeldahl Nitrogen Concentration (mg/L) at Wakaw Lake (August 1979 - June 1980). Standard Errors Indicated.

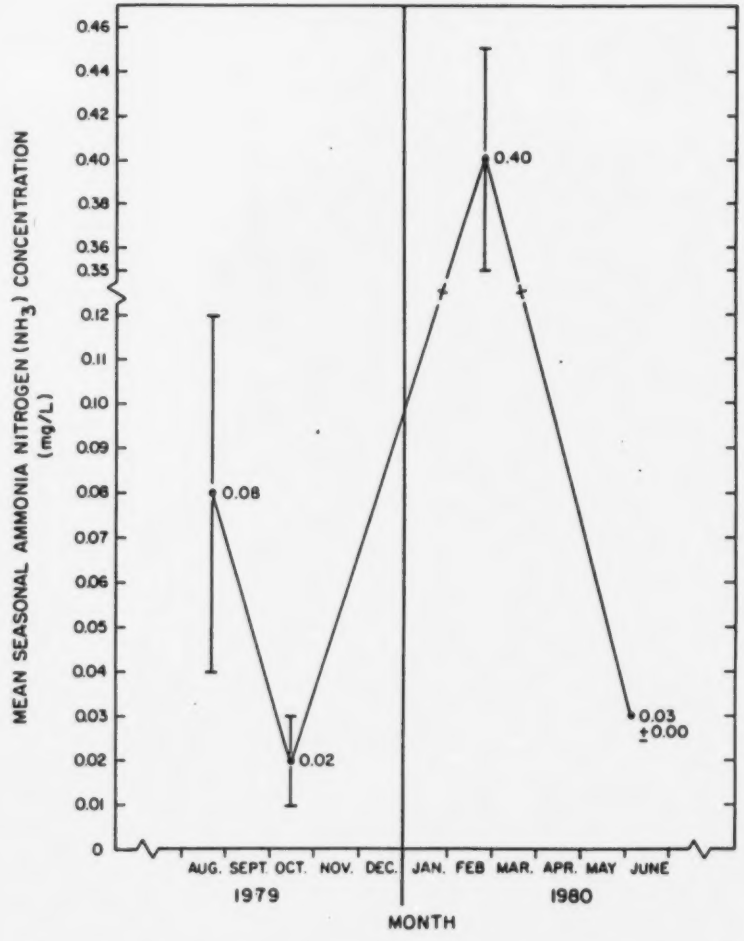

Figure 7b : Mean Seasonal Ammonia Nitrogen Concentration (mg/L) at Wakaw Lake (August 1979 - June 1980). Standard Errors Indicated.

The release of organic nitrogen from decaying plant and animal material and concurrent elevation in NH_3-N concentration during the ice cover period also likely accounts for the high TKN concentrations recorded during February, 1980.

Ammonia nitrogen (NH_3-N) is usually present in low (less than 0.1 mg/L) quantities in non-polluted well oxygenated water. Mean concentrations of NH_3-N during February 1980 reached as high as 0.86 mg/L at station No. 5. Water levels of NH_3-N in aquatic systems are of concern since they add to the biochemical oxygen demand and can be toxic to aquatic organisms. High levels of ammonia reduce the oxygen carrying capacity of the blood in fish and may result in their suffocation. Ammonia toxicity is related to the amount of undissociated NH_3 present. The relative proportion of the toxic NH_3 increases with pH. Based on U.S. Environmental Protection Agency water quality criteria (Anon., 1980) for determining the amount of toxic un-ionized NH_3 present, ammonia concentrations observed translate to toxic levels well below the limit of 0.02 mg/L suggested for the protection of freshwater aquatic life (Anon., 1973).

Mean seasonal NO_2 + NO_3-N concentrations (see Appendix D, Table D-4) ranged from less than 0.03 mg/L during the

October, 1979 and February, June, 1980 surveys, to 0.04 mg/L in August, 1979.

The low mean concentration noted in October, February and June may in part be due to reduced bacterial nitrification during periods of low water temperature. Anaerobic decomposition near the substrate during these periods also may have contributed to low NO_2 + NO_3-N concentrations.

Total kjeldahl nitrogen concentration and ammonia nitrogen concentration determinations appeared to be slightly higher at several of the shallow water stations than at deep water stations. However consistent spatial trends within Wakaw Lake regarding TKN, NH_3-N or NO_2 + NO_3-N data could not be determined.

4.3.3 Chlorophyll "a"

Chlorophyll "a" is the primary photosynthetic pigment of all oxygen evolving photosynthetic organisms (Wetzel, 1975). Chlorophyll data has been used in attempts to characterize algal community age and structure (Odum et al, 1985; cited by Lind, 1979), photosynthetic rates (Ryther and Yentsch, 1957) and the quantification of phytoplankton standing crop (Small, 1961). Since chlorophyll presence and determination is dependent on many variables, qualitative interpretation of such data is generally more appropriate.

Chlorophyll "a" is present in all algae and is generally the dominant photoreceptor. The concentration of chlorophyll "a" in water therefore can be used to estimate the relative abundance of the phytoplankton community. Consequently, chlorophyll "a" concentration is a useful general indicator of trophic status (lake fertility). High chlorophyll "a" concentrations are often indicative of eutrophic waters whereas low concentrations are characteristic of oligotrophic waters.

Seasonal chlorophyll "a" concentration for Wakaw Lake are summarized in Appendix D (Table D-5). Mean seasonal chlorophyll "a" concentration ranged from a low of 2.5 ug/L during February, to a high of 12.6 ug/L during June, 1980 (see Figure 8). The second highest mean chlorophyll "a" concentrations occurred during the August, 1979 survey. There appeared to be no significant difference between the mean chlorophyll "a" concentrations observed during October, 1979. The highest chlorophyll "a" concentration recorded on a single day (21.0 ug/L) occurred at sampling station No. 7 during the June, 1980 survey period. Probability distributions for trophic categories proposed by Vollenwieder and Kerekes (1980) suggest that this maximum concentration is most likely (50%) indicative of upper mesotrophic waters.

The mean annual chlorophyll "a" concentration for Wakaw Lake during this study was 7.2 ug/L. Based on the Trophic State Index devised by Carlson (1977), this chlorophyll "a" concentration translates into a TSI value of 50. According to findings by Rast and Lee (1978), this TSI value is characteristic of a lower range eutrophic lake.

Several subtle spatial trends regarding chlorophyll "a" concentrations within Wakaw Lake are apparent. Mean annual chlorophyll "a" concentration progressively increased from 6.0 ug/L near the lake's west end (Station No. 1) to 8.5 ug/L at Stations No. 5-7 and 8-10 near the lake's mid-point. Mean annual chlorophyll "a" concentration then declined to a low of 2.8 ug/L at Station No. 15 located near the east end (see Figure 9). This trend for increasing chlorophyll concentration towards the lake's centre from east and west ends was evident on a seasonal and annual basis (see Appendix D, Table D-6).

There also was a trend regarding water depth. Mean annual chlorophyll "a" concentration at sampling stations located in the water greater than 2 metres deep was considerably higher than that of stations with depth less than 2 metres. These means were 10.6 ug/L and 6.9 ug/L respectively. The lower chlorphyll "a" concentrations recorded at shallow water stations may be related to the

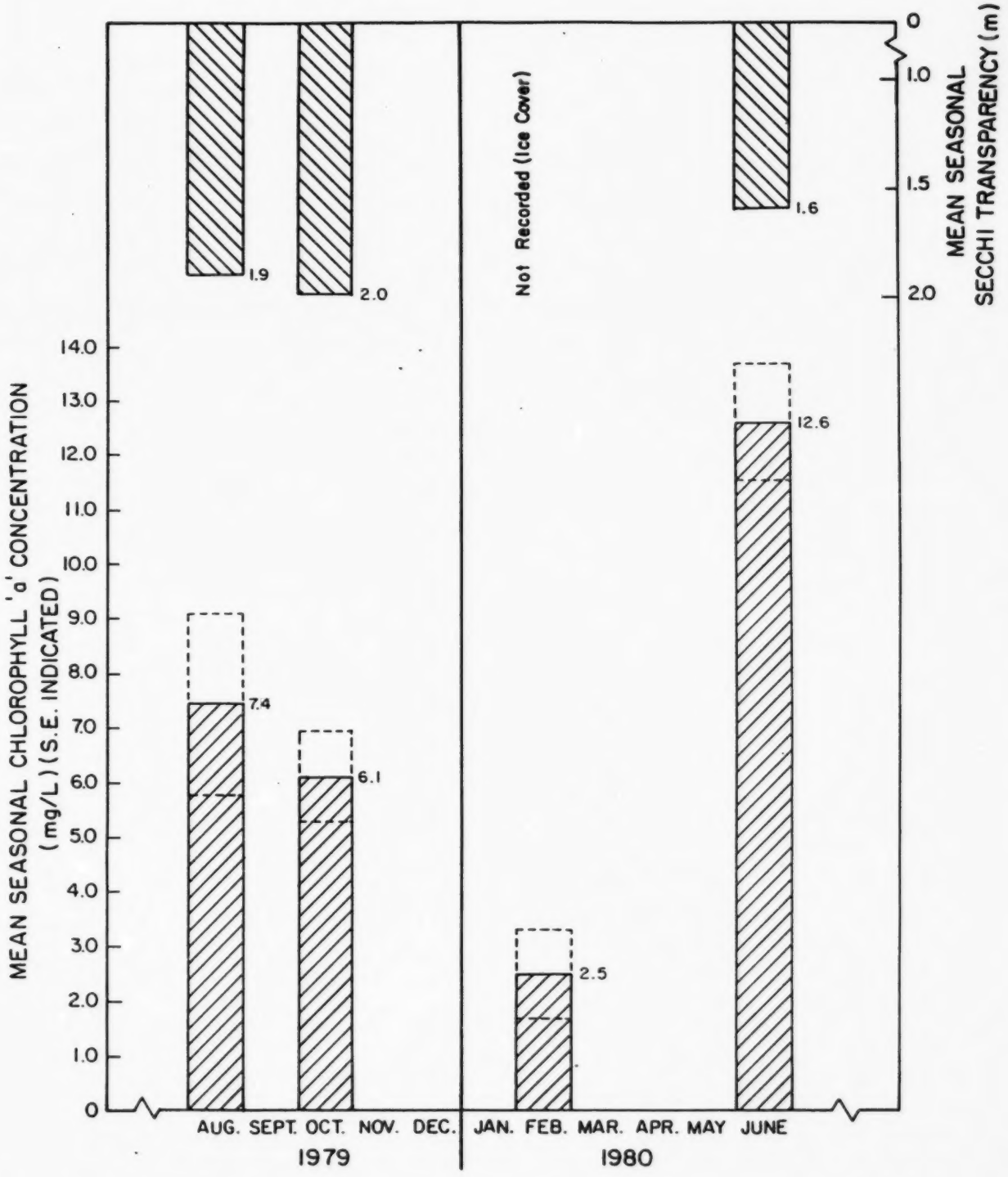

Figure 8 : Mean Seasonal Chlorophyll 'a' Concentration and Secchi Transparency at Wakaw Lake (August 1979 - June 1980)

relative abundance of rooted macrophyte growth in these areas. Algae growth in areas of abundant macrophyte growth are characteristically lower than in open water areas. This may be related to the large quantity of nutrients utilized by macrophyte growth, shading, and reduced water movement (circulation) in these areas.

4.3.4 Secchi Transparency

Water transparency declines as a lake becomes more fertile. This is a direct result of increased suspended particulate matter, primarily of biological origin. Phytoplankton is generally the dominant component of such particulate matter. Changes in water transparency therefore are often indicative of changes in lake productivity or trophic status. This is particularly applicable to long-term changes.

Water transparency is generally discussed in terms of visibility. Water visibility is a measure of the depth to which an observer can see into the water. This depth is commonly estimated with a simple device called a Secchi disk which is lowered through the water on a line marked with metric graduations. In principal, the deeper the disk is viewed, the clearer the water, the fewer suspended particulates of biological origin present, and the assumption of lower trophic state.

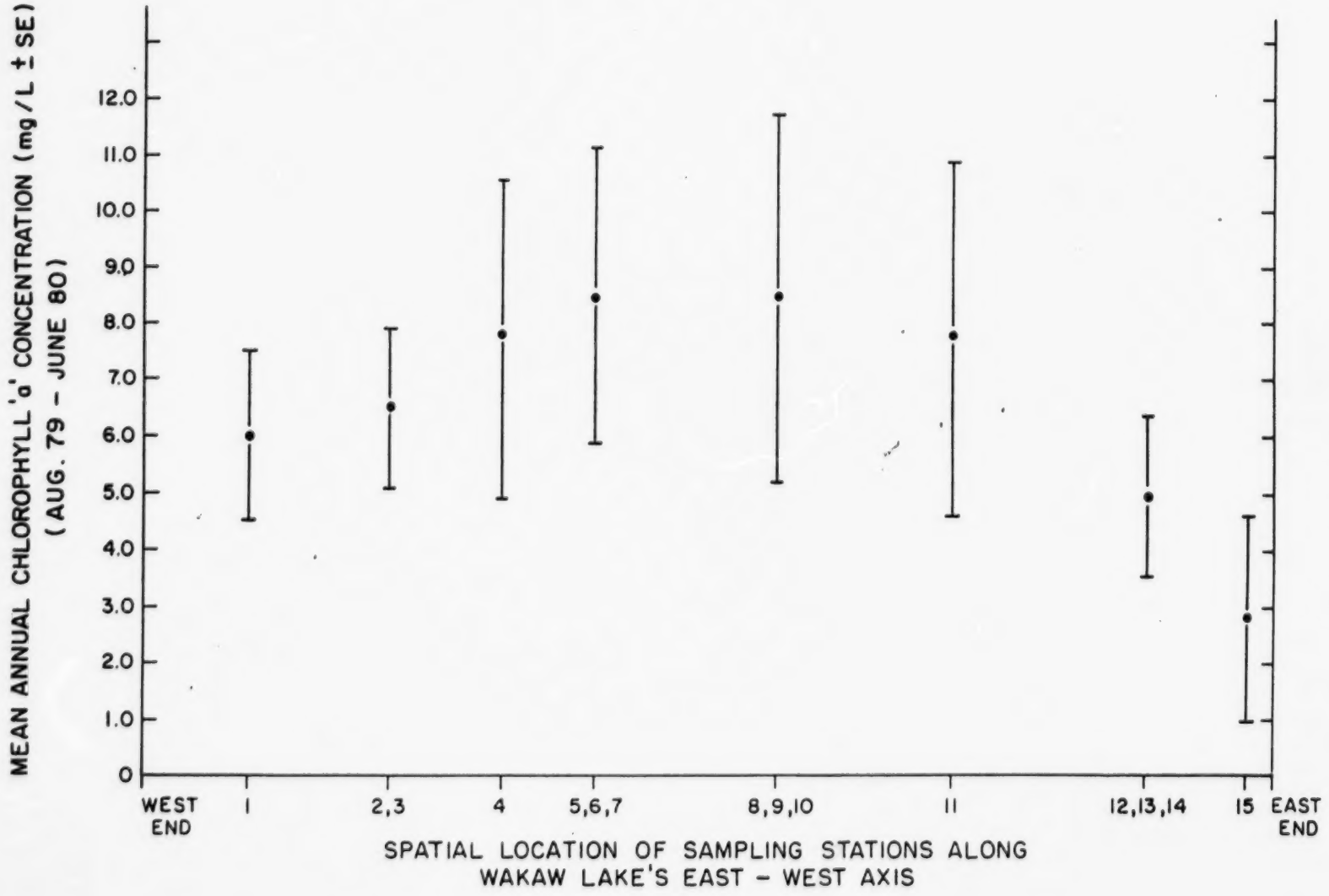

Figure 9 : Spatial Trends Regarding Mean Annual Chlorophyll 'a' Concentration at Wakaw Lake, (Aug. 79 - June 80). Standard Errors Indicated.

Mean seasonal Secchi transparency for each sampling station is presented in Appendix D, (Table D-1). Secchi transparency at many of the shallow water stations could not be determined since the bottom substrate was still visible from the surface. Mean seasonal Secchi transparency at "deep water" stations was highest (2.0 m) during October, 1979 and lowest (1.6 m) during the June, 1980 survey. Mean Secchi transparency during the ice free season was 1.8 m. This value is characteristic of slightly eutrophic waters. Also, based on Carlson's (1977) Trophic State Index system, this mean value translates into a TSI number of 52. Studies by Rast and Lee (1978) suggest that such a TSI value is indicative of slightly to moderately eutrophic lakes.

Secchi transparency results were negatively correlated with mean chlorophyll "a" concentrations for the ice-free period (see Figure 8). This is consistent with the inverse relationship which exists between Secchi transparency and suspended particulate matter.

4.4 Biota

4.4.1 Phytoplankton

The term "phytoplankton" refers to individual or colonial forms of algae which for the most part, drift passively within a water system. Phytoplankton are an integral

component of aquatic systems, being a primary link in the aquatic food chain. It should be noted, however, that the significance of phytoplankton decreases as the volume of water decreases; in smaller shallower waters, the benthic and attached algal forms become increasingly important. Epiphytic algae (those attached to submersed aquatic plants) are of major significance in lakes where abundant aquatic plant growth is present.

Characteristic of many Saskatchewan lakes, Wakaw Lake has an abundant algae population, particularly during the spring and summer. A potential concern therefore is related to the inherent impacts associated with algal overabundance. The ability of algae for prolific growth rates can often result in nuisance impacts. These problems can occur during both active growth and decay of algae. Potential undesirable effects of algal metabolism and decay on aquatic ecosystems as outlined by Dehavay (1983) include:

- increase in water colouration due to algal pigments;
- increase in water colouration due to algal pigments;
- pH may become strongly alkaline resulting from CO_2 (carbon dioxide) extraction during photosynthesis;
- may impart an undesirable taste and odour to water;
- oxygen levels within the water system may be seriously reduced by the decomposition of algae.

The relative abundance of phytoplankton also can provide an indication of a lake's trophic status; eutrophic waters generally having a more abundant phytoplankton population that meso or oligotrophic waters. The survey of Wakaw Lake's phytoplankton community was conducted to provide a comprehensive historical data base. This data base will allow documentation of future changes in algal species composition and relative seasonal abundance. Such a data base also may provide indications of trophic status changes. A complete overview of all algae identification and enumeration results compiled during the Wakaw Lake study, are available from Saskatchewan Environment's computerized BIODAT file records. A brief summary and interpretation of these results follows.

A summary of the algae varieties observed within Wakaw Lake during the study period is presented in Table 1. A total of 109 algal varieties were identified. Eighty of these were identified to species level while 29 were identified only to genus level. The 109 algal varieties identified represented 70 genera.

On an overall basis, the greatest species diversity (37 spp) occurred within the phylum Chlorophyta (green algae). In contrast, the lowest diversity (2 spp) occurred within the phylum Euglenophyta (euglenoids) (see Table 1). The

phyla Chrysophyta (yellow-green algae) and Cyanophyta (blue-green algae) were represented by 32 and 30 algal varieties respectively.

On a seasonal basis, observed species diversity was highest during February 1980 and lowest during August 1979 (see Table 2). However, the opposite was the case regarding total algae volume (an indicator of biomass) (see Appendix E, Table E-1). An inverse relationship occurred between species diversity and total cell volume.

The highest seasonal species diversity within a phylum (29 spp) occurred during February 1980 in the Chrysophyta. Diatoms accounted for 25 of the 29 varieties observed. The highest species diversity during June 1980 occurred within the phylum Chlorophyta (23 spp). On the basis of species numbers, Chlorophyta and Cyanophyta were equally abundant during August 1979 (see Table 2).

Somewhat unexpectantly, the greatest diversity within the phylum Cyanophyta occurred during February 1980. Growth of this algal group is usually most common during summer. It should be noted, however, that total cell volume within the phylum Cyanophyta was lower during February than either June 1980 or August 1979. This discrepancy again seems to indicate an inverse relationship between algal species diversity and actual volumetric abundance.

Total phytoplankton cell density (No./L) and total cell volume (u^3/L) data collected during the study period are summarized in Appendix E (Tables E-2 and E-1). Since the cell size of different algae may vary greatly, it is important to consider both cell density and volume when determining relative dominance of particular phyla or species. For the same reason, cell volume is a better indicator of biomass than cell number.

Based on totals of each survey period, cell volume was highest during August 1979 (246.3×10^9 u^3/L) and lowest during February 1980 (19.0×10^9 u^3/L). The most abundant phyla (volumetrically) during each of these survey periods was Cyanophyta. On an overall basis (all survey periods combined), the phylum Cyanophyta displayed the highest total cell volume. The phylum Euglenophyta was the least abundant (numerically and volumetrically) during all survey periods.

Table 3 summarizes the total relative numeric and volumetric phytoplankton composition of Wakaw Lake according to taxanomic phyla. Among the Chlorophyta, per cent composition by cell number was consistently higher than that by volume. The overall composition (all surveys combined) by these parameters was seven and one per cent respectively. On an overall basis, Chrysophyta accounted

Table 1: Phytoplankton Genera and Species Observed in Wakaw Lake (August 1979-June 1980) (n = 109).

Chlorophyta (n = 37) (Green algae)	Cyanophyta (n = 30) (blue-green algae)
Ankistrodesmus spiralis	Anabaena flos-aquae
Botryococcus braunii	Anabaena sp.
Bulbochaete sp.	Aphanocapsa delicatissima
Chlamydomonas sp.	A. elachista
Closterium sp.	A. rivularis
Coelastrum sp.	Aphanothece clathrata
Cosmarium sp.	A. nidularis
C. tetrapedia	Chroococcus dispersus
Dictyosphaerium pulchellum	C. limneticus
D. simplex	Coelosphaerium Kuetzingianum
Gloeocystis sp.	C. naegelianum
Kirchneriella contorta	Gomphoshaeria aponina
Monoraphidium contortum	G. lactustris
M. minutum	Lyngbya limnetica
Mougeotia sp.	Merismopedia glauca
Oocystis borgei	M. punctata
O. crassa	M. tenuissima
O. lacustris	Microcystis aeruginosa
O. pusilla	Oscillatoria agardhii
O. submarina	O. angusta
Pediastrum boryanum	O. angustissima
P. duplex	O. limnetica
Planktosphaeria gelatinosa	O. limosa
Scenedesmus acuminatus	O. tenuis
S. acutus	Phormidium mucicola
S. balatonicus	Pseudanabaena catenata
S. ecornis	Radiocystis geminata
S. incrassatulus	Synechococcus sp.
S. intermedius	Synechocystis sp.
S. quadricauda	
S. securiformis	Euglenophyta (n = 2) (Euglenoids)
Schroederia judayi	Euglena acus
Selenastrum minutum	Euglena sp.
Sphaerocystis schroeteri	
Tetraedron minimum	

(continued)

Table 1 (continued)

Chrysophyta* (n = 32)
(yellow-green algae)
Achnanthes sp.
Amphiprora alata
A. paludosa
Campylodiscus clypeus
Chaetoceros elmorei
C. muelleri
Chrysamoeba sp.
Chrysochromulina parva
Cocconeis sp.
Cyclotella bodanica
Cymbella sp.
Diatoma elongatum
D. vulgare
Epithemia turgida
Fragilaria crotonensis
Fragilaria sp.
Gomphonema sp.
Gyrosigma sp.
Kephyrion sp.
Mallamonas sp.
Navicula sp.
Nitzschia acicularis
N. sigmoidea
Ochromonas sp.
Pseudokephyrion entzii
Rhoicosphenia curvata
Rhopalodia gibba
Stauroneis sp.
Stipitococcus vas
Surirella sp.
Synedra acus
S. ulna

Pyrrhophyta (n = 8)
(Dinoflagellates)
Ceratium hirundinella
Chroomonas sp.
Cryptomonas marssonii
Cryptomonas sp.
Gymnodinium sp.
Katablepharis sp.
Rhodomonas minuta
Rhodomonas sp.

* Includes diatoms (presently belong to separate phylum Bacillariophyta).

Table 2: Phytoplankton Species Diversity Observed at Wakaw Lake (all stations combined) 1979-80.

Phylum	Number of species* observed		
	August 20/79	February 25, 26, 27/80	June 3/80
Chlorophyta	21	18	23
Chrysophyta	17	29	14
Cyanophyta	21	24	12
Euglenophyta	0	1	1
Pyrrhophyta	3	1	4
Total	62	73	64

* Numbers presented include varieties which were identified only to genus level.

for the highest proportion of phytoplankton cell numbers (80%). In contrast, however, the Chrysophyta represented only 11% of the overall phytoplankton volume. This again demonstrates the importance of considering both cell number and cell volume when determining the relative composition and dominance of an algal group.

Among the Cyanophyta, per cent composition by cell volume was consistently higher than that by cell number. On an overall basis, the per cent composition by these parameters was 83 and 10 per cent respectively. These numbers indicate that the observed Cyanophytes were (on average) larger than members of other phyla. These numbers also indicate that the phytoplankton of Wakaw Lake is dominated by blue-green algae, a characteristic of eutrophic lakes.

Table 3: Total Relative (Per Cent) Numeric and Volumetric Composition of Phytoplankton Phyla Within Wakaw Lake (all stations combined) 1979-80.

Phylum	August 20/79		Feb. 25-27/80		June 3/80		Overall	
	% by Num.	% by Vol.	% by Num.	% by Vol.	% by Num.	% by Vol.	% by Num.	% by Vol.
Chlorophyta	8	N	24	3	7	3	7	1
Chrysophyta	68	2	21	21	84	52	80	11
Cyanophyta	13	94	53	69	7	39	10	83
Euglenophyta	NF	NF	N	N	N	N	N	<1
Pyrrhophyta	11	4	2	7	2	6	3	4

N - Negligible
NF - Not Found

During August 1979, Chrysophyta was dominant numerically while Cyanophyta was dominant volumetrically. Chrysophytes were dominant on the basis of both cell numbers and volume during the June 1980 survey period.

4.4.2 Macrophytes

The term "macrophyte" refers to all the large macroscopic plants of aquatic systems. They are primarily vascular but also include large algae such as Chara and Nitella species. Macrophytes are an important component of the aquatic ecosystem, contributing significantly to the productivity of lakes. They also play an important role in the regulation of metabolism of the whole lake ecosystem. Despite the importance of macrophytes in aquatic systems,

prolific growth can cause numerous nuisance impacts. These include interference with boating, swimming, angling, reduced aesthetic value of lake shore, increased nutrient cycling and increased water loss to the atmosphere due to evapotranspiration.

A qualitative assessment of aquatic macrophyte growth within Wakaw Lake was conducted on August 21, 1979. Observations regarding species presence and relative abundance were made along four transect lines (see Figure 2).

Characteristic of most shallow lakes, Wakaw Lake contains an abundant macrophyte population. Observed species diversity, however, was not exceptionally high. A total of eight submergent and one emergent species were noted (see Table 4). These nine species represented eight genera.

Based on relative abundance, Chara sp. (Stonewort) appears to be the dominant species within Wakaw Lake. Chara sp. was observed at all transect locations. This genus was particularly abundant at transects #1 and 2. Chara sp. covered the bottom all across the lake at transect #1. Growth of this species extended right to the south shore's edge. Potamogeton pectinatus L. (Sago pondweed) was the second most abundant species observed in Wakaw Lake. This

Table 4: Aquatic Macrophyte Species Observed in Wakaw Lake, August 21, 1979

Scientific Name	Common Name
Ceratophyllum demersum L.	Coontail
Chara sp *	Stonewort
Myriophyllum exalbescens Fern.	Northern water milfoil
Potamogeton pectinatus L.	Sago pondweed
P. richardsonii Rydb. Benn.	Richardson's pondweed
Ruppia maritima L.	Widgeon grass
Sagittaria cuneata Sheld.	Arrowhead
Typha latifolia L.	Cattail
Utricularia vulgaris L.	Bladderwort

* Chara sp. is a macrophytic algae.

rooted submergent was present at all transects and appeared to be most abundant along the lake's north shore. Potamogeton pectinatus was most commonly observed in waters ranging from 1.0-2.5 m in depth.

The non-rooting submergent, Ceratophyllum demersum L. (Coontail), also was commonly observed in Wakaw Lake. This species was noted at all transects with exception of transect #1. The observed depth distribution for this species ranged from shore's edge to approximately 4.0 metres. Ceratophyllum demersum was commonly found in association with Chara sp., and together were most often the dominant species present at water depths in access of

2.5 metres. It should be noted that no "rooted" macrophyte growth was observed beyond the 3.0 m depth. Macrophyte depth distribution is directly correlated with light penetration. Therefore, the relatively high turbidity of water due to phytoplankton growth during the summer may deter rooted macrophyte growth beyond the 3.0 m depth.

Myriophyllum exalbescens Fern. (Northern water milfoil) was observed at all transects but growth was generally more sparse than that of P. pectinatus and C. demersum. Myriophyllum exalbescens was often present in mixed beds with P. pectinatus and C. demersum. This species appeared to be equally abundant along the north and south shores. The abundance of macrophytic growth in the littoral regions of Wakaw Lake may act to reduce phytoplankton growth in these shallow regions. Spatial trends regarding chlorophyll "a" concentration (section 4.3.3) indicated lower phytoplankton productivity at shallow stations than at mid-lake stations. Prolific macrophyte growth can inhibit algae development due to shading effects and uptake of growth limiting nutrients such as phosphorus.

Abundant macrophyte growth is characteristic of eutrophic waters. Prolific growth within Wakaw Lake ultimately contributes to progressive eutrophication due to nutrient cycling during periods of plant decomposition. Also,

aerobic decomposition of large quantities of plant material can result in oxygen depletion and elevation of NH_3 concentrations due to the resulting anaerobic breakdown of plant material.

4.4.3 Benthos

Benthos is the collective term for organisms that inhabit the bottom substrata of lakes, ponds and streams. Benthic organisms play several important roles in the aquatic community:

(1) they are involved in the mineralization and recycling of organic matter produced in the water above or brought in from external sources;

(2) many organisms such as insect larval forms provide a major food source for small fish.

Quantitative studies of a lake's benthos are often useful as an indirect indicator of that lake's productivity and trophic status. Also, gradual changes in the density and composition of the lake's benthic community may be indicative of changes in water quality and trophic status. In principal, lakes with highly productive limnetic and littoral zones generally have an impoverished benthic fauna. This is due to the anaerobic conditions characteristic of such lake sediments, where, the amount of organic matter reaching the bottom is greater than can be utilized by the bottom fauna.

A total of 18 distinct taxa of benthic organisms were observed in Wakaw Lake sediments collected during August 1979. The taxonomy of these organisms is summarized in Table 5. Sixteen organisms were identified to genus level.

Numerically, Chironomidae (midge) larvae were the most abundant organisms present in benthic samples (see Table 6). This family of insects also exhibited the greatest diversity with four genera being identified. Of ten stations sampled, only station #12 had an absence of chironomids. The next most abundant benthic organisms observed belonged to the class Oligochaeta. This taxonomic group (aquatic earthworms) accounted for 14% of the total bottom fauna observed. It should be noted however, that a single sample (from station #7) accounted for all Oligochaetes observed. This pattern of abundant chironomid and oligochaete organisms is characteristic of productive lakes.

Although present, leeches, nematodes and snails were very uncommon. Amphipods (freshwater shrimps) accounted for only 3% of the benthic fauna. Mendis (1956) found that chironomids and amphipods were the most abundant benthic organisms present in Wakaw Lake on a dry weight basis. Note however, that species composition and density can vary considerably between season and years. Timms (1985;

Table 5: Taxonomy of Benthic Organisms Observed in Sediments Collected at Wakaw Lake, August 21, 1979.

Phylum NEMATODA (round worms)
Family Dorylaimidae
1. *Eudorylaimus* sp.

Phylum ANNELIDA
Class Hirudinea (leeches)
Order Hirudinia
Fam. Glossphomiidae
2. *Glossiphonia* sp.
3. *Helobdella* sp.
4. *Placobdella* sp.

Class Oligochaeta
5. (aquatic earthworms)

Phylum MOLLUSCA
Class Gastropoda (snails)
Fam. Lymnaeidae
6. *Lymnaea* sp.

Class Pelecypoda (clams)
Fam. Physiidae
7. *Physa* sp.
Fam. Sphaeriidae
8. *Pisidium* sp.

Phylum ARTHROPODA
Class Crustacea
Order Amphipoda (freshwater shrimps)
9. *Gammarus* sp.
10. *Hyalella azteca*
Order Ostracoda
11. (fairy shrimps)

Class Insecta
Order Diptera (flies)
Fam. Chaoboridae (Phantom midges)
12. *Chaoborus* sp.
Fam. Chironomidae (midges)
13. *Cryptochironomus* sp.
14. *Chironomus (Chironomus)* sp.
15. *Procladius* sp.
16. *Phaenopsectra (Tribelos)* sp.

Order Odonata (dragonflies and damselflies)
Fam. Coenagrionidae
17. *Enallagma* sp.

Order Trichoptera (caddisflies)
Fam. Phryganeidae
18. *Oligotricha* sp.

Table 6: Summary of Benthic Fauna Observed in Sediment Samples Collected at Wakaw Lake, August 21, 1979 (Sampled by Ekman Dredge[1]).

Taxonomic Group	Common Name	Number of Individuals Counted[2] Sampling Station 1	5	6	7	8	9	10	12	13	14	Total	%
Amphipoda (O)	Freshwater shrimps	-	-	-	-	1	-	9	1	-	-	11	3
Ostracoda (O)	Fairy shrimps	2	-	-	-	-	2	3	-	9	5	21	5
Hirundinea (C)	leeches	-	-	-	-	3	-	1	-	2	-	6	1
Nematoda (P)	roundworms	-	4	-	-	-	-	-	-	-	-	4	1
Oligochaeta (C)	aquatic earthworms	-	-	-	64	-	-	-	-	-	-	64	14
Gastropoda (C)	snails	-	-	-	-	-	-	-	-	1	-	1	<1
Pelecypoda (C)	clams	-	3	-	-	12	-	-	1	-	-	16	4
Chaoboridae (F)	phantom midges	-	-	2	-	-	26	-	-	-	-	28	6
Chironomidae (F)	midges	7	40	7	36	17	4	156	-	11	4	282	62
Odonata (O)	dragon flies, damsel flies	-	-	-	-	14	-	-	2	-	-	16	4
Trichoptera (O)	caddis flies	-	-	-	-	1	-	-	-	-	-	1	<1
Total		9	47	9	100	48	32	169	4	23	9	450	100
Mean Number of Benthic Organisms (No./m^3) = 1937													

1 sampling area of dredge - 232 cm^2.
2 counts include adult, larvae, nymphs and pupae.

P - Phylum
C - Class
O - Order
F - Family

unpublished) found that Wakaw Lake exhibited a pattern of growth characterized by rich benthos biomass during winter and spring and relatively low biomass during the summer. This may account for the moderately low numbers (1937/m^3) of benthic organisms observed during the August sampling period.

4.4.4 Fish

Seven species of fish have been recorded in Wakaw Lake. These species are northern pike (Esox lucius), walleye (pickerel) (Stizostedion vitreum), yellow perch (Perca flavescens), common sucker (Catastomus commersoni), brook stickleback (Culaea inconstans), spottail shiner (Notropis hudsonius) and Iowa darter (Etheostoma exile). Studies by Mendis (1956) indicated that pickerel were the dominant fish species in Wakaw Lake. The next most abundant species was the yellow perch. Perch growth rates, as determined from examination of netted fish, were low. The low growth rates observed may be due to overcrowding (Mendis, 1956).

Recreational fish management studies were conducted by Saskatchewan Parks and Renewable Resources in 1969, 1974, 1975 and most recently in 1983. Catch comparisons based on gill net sets indicate that walleye was still the dominant species present in 1983. However, sucker numbers recorded in 1983 had about doubled that of previous studies and were

comparable to that of walleye. The sucker population present in 1983 was not considered to be at a problem level since game fish still outnumbered suckers. Catch comparisons also indicated that perch numbers had increased considerably by 1983. Although numerous in 1983, perch were small and represented a poor angling population.

Mendis (1956) also studied the food and feeding habits of Wakaw Lake fish. The food of most sampled walleye was smaller fish such as young perch, suckers, and adult sticklebacks. The pike also had fed primarily on smaller fish. Perch stomach contents indicated a more varied diet than either walleye or pike. Analysis of stomach contents showed a preference for small fish like sticklebacks, chironomid larvae and amphipods. The common sucker feeds on bottom organisms and is therefore often useful as an indicator of benthos composition. The stomachs of collected suckers contained mainly amphipods indicating an abundance of these within Wakaw Lake. However, analysis of benthic samples collected during August 1979 did not confirm this (see section 4.4.3).

Spawning appears to occur both within the lake and in the outlet. Northern pike and suckers have been observed spawning in April and May at the outflow to several hundred metres downstream. It is likely though that the majority

of spawning activity of Wakaw Lake fish occurs within the lake itself. The shallows at the west end, particularly north of the islands and the north arm; and the shallows of the east end of the lake provide spawning grounds and nursery areas for fish (Anon., 1975).

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Table A-1: Wakaw Lake Levels During Ice-Free Months (1966-1982).

	Month					
Year	May	June	July	Aug.	Sept.	Oct.
1966	-	509.53	509.52	509.49	509.42	509.40
1967	-	509.40	509.35	509.26	509.19	509.15
1968	509.44	509.41	509.38	509.37	509.41	509.41
1969	509.64	509.62	509.55	509.49	509.46	509.96
1970	509.36	-	509.33	509.24	509.15	509.11
1971	509.33	509.34	509.34	509.31	509.23	509.19
1972	509.51	509.41	509.36	509.30	509.21	509.18
1973	509.39	509.44	509.43	509.35	509.31	509.29
1974	509.56	509.49	509.40	509.35	509.34	509.30
1975	509.54	509.46	509.34	509.26	509.21	509.18
1976	509.38	509.36	509.31	509.22	509.16	509.11
1977	509.31	509.26	509.18	509.12	509.15	509.17
1978	509.38	509.37	509.30	509.27	509.27	509.25
1979	509.66	509.54	509.43	509.33	509.27	509.22
1980	509.37	509.35	509.30	509.23	509.18	509.15
1981	509.31	509.27	509.23	509.19	509.10	509.10
1982	509.30	509.38	509.34	509.30	509.27	509.27
$\bar{x}$	509.43	509.41	509.36	509.30	509.25	509.23

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Table B-8	Mean Seasonal Manganese (Mn) Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Table B-1: Summary of Mean Diurnal Temperature, Dissolved Oxygen and Per Cent Saturation in Wakaw Lake, Station 4 (deep water station) (August, 1979-June, 1980).

Depth (m)	August 20-22, 1979			October 15-17, 1979			February 25-27, 1980			June 2-4, 1980		
	T (°C)	DO (mg/L)	% O_2 Sat.	T (°C)	DO (mg/L)	% O_2 Sat.	T (°C)	DO (mg/L)	% O_2 Sat.	T (°C)	DO (mg/L)	% O_2 Sat.
surface	19.8	9.0	100	8.1	10.5	93	0	8.4	61	15.3	8.1	84
1	20.0	9.0	100	8.1	10.3	92	0	8.1	58	15.3	8.0	84
2	19.7	9.4	100	8.1	10.3	92	0	8.0	58	15.3	8.0	85
3	19.3	8.3	93	8.3	10.2	91	0	7.9	58	15.3	8.1	86
4	18.9	7.5	85	8.3	10.3	92	0	7.9	58	15.3	8.1	85
5	18.8	7.0	82	8.3	10.3	92	0	7.9	57	15.3	8.0	85
6	18.0	6.6	76	8.3	10.3	92	0	6.7	41	15.3	8.0	84
7	17.8	5.4	61	8.3	10.3	92	0	5.0	36	15.3	8.1	85
8	17.7	5.2	58	8.2	10.2	92	0	3.6	26	15.3	8.0	84
9	17.4	3.9	45	8.2	10.2	91	1.0	1.6	14	15.3	7.8	81
10	17.1	2.9	33	8.2	9.9	89	1.0	1.2	9	15.3	8.1	81
11	16.3	1.1	13.6	8.0	9.9	89	1.2	0.7	7	-	-	-
12	16.0	1.0*	11*	-	-	-	1.2	0.7	5	-	-	-

* Several samples at the 12 m depth indicated 0.0 DO and 0% saturation.

Table B-2: Mean Seasonal Total Organic Carbon Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	19	18	15	NR
2	16	16	19	19
3	13	17	15	19
4	12	17	16	19
5	13	17	13	18
6	11	17	15	18
7	12	16	7	17
8	12	17	10	18
9	13	18	18	19
10	32	18	18	18
11	13	17	14	18
12	14	17	17	18
13	12	18	16	18
14	14	18	13	19
15	18	17	18	18
16	5	18	NR	NR
Seasonal Mean	14	17	15	18

NR - Not Recorded

Table B-3: Mean Seasonal Conductivity[1] (us/cm) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	3350	2620	3730	NR
2	3380	3020	3230	3180
3	3360	3000	3130	3190
4	3380	3000	3080	3190
5	3370	3000	2800	3190
6	3340	3000	2700	3200
7	3350	3000	2070	3180
8	3360	3000	3030	3170
9	3340	3000	3120	3200
10	3360	3000	2970	3180
11	3360	3000	3200	3230
12	3380	3000	3070	3240
13	3390	3000	2900	3190
14	3380	3000	3230	3210
15	3390	3000	3200	3300
16	3070	2633	NR	NR
Seasonal Mean	3350	2960	3020	3200

1 All mean conductivity values rounded off to the nearest ten.

NR - Not Recorded

Table B-4: Mean Seasonal Chloride Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	58	62	79	NR
2	59	62	66	54
3	59	61	64	54
4	59	59	63	54
5	59	60	59	53
6	60	59	59	54
7	58	62	57	54
8	59	61	63	54
9	58	61	62	54
10	58	59	61	54
11	60	61	61	55
12	59	63	63	56
13	61	64	61	54
14	60	61	59	54
15	62	61	64	56
16	50	61	NR	NR
Seasonal Mean	59	61	63	54

NR - Not Recorded

Table B-5: Mean[1] Seasonal pH at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	9.4	8.6	7.3	NR
2	8.8	8.2	7.5	8.4
3	8.3	8.2	7.7	8.4
4	8.1	8.1	7.7	8.4
5	8.1	8.1	7.6	8.4
6	8.2	8.2	7.7	8.4
7	8.3	8.2	7.6	8.4
8	8.2	8.3	7.7	8.4
9	8.2	8.2	7.9	8.3
10	8.3	8.2	7.8	8.4
11	8.3	8.2	7.9	8.3
12	8.4	8.3	8.0	8.5
13	8.4	8.4	7.9	8.4
14	8.3	8.3	7.7	8.4
15	9.0	8.3	7.8	8.6
16	7.6	8.0	NR	NR
Seasonal Mean[1]	8.6	8.3	7.7	8.4

1 By definition, pH values cannot be averaged arithmetically. Means were therefore estimated by the logarithm of the reciprocals.

NR - Not Recorded

Table B-6: Mean Seasonal Total Alkalinity ($CaCO_3$) Concentration (mg/L) at Sampling Stations on Wakaw Lake (October, 1979-February, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	NR	138	244	NR
2	NR	152	203	NR
3	NR	157	167	NR
4	NR	162	193	NR
5	NR	162	254	NR
6	NR	162	216	NR
7	NR	165	223	NR
8	NR	159	197	NR
9	NR	159	179	NR
10	NR	160	190	NR
11	NR	157	174	NR
12	NR	158	170	NR
13	NR	161	169	NR
14	NR	159	213	NR
15	NR	154	168	NR
16	NR	175	NR	NR
Seasonal Mean	NR	159	197	NR

NR - Not Recorded

Table B-7: Mean Seasonal Iron (Fe) Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	0.2	0.2	0.2	NR
2	0.2	0.2	0.2	<0.1
3	0.2	0.2	NR	0.1
4	0.2	0.2	0.5	0.1
5	0.2	0.2	NR	<0.1
6	0.2	0.2	NR	<0.1
7	0.4	0.1	NR	0.1
8	0.3	0.2	NR	<0.1
9	0.3	0.1	0.2	<0.1
10	0.2	<0.1	NR	0.2
11	0.2	0.1	0.2	<0.1
12	0.3	0.2	NR	<0.1
13	0.2	0.1	NR	<0.1
14	0.2	0.2	NR	<0.1
15	0.2	0.3	NR	<0.1
16	1.4	0.6	NR	NR
Seasonal Mean	0.3	0.2	0.3	0.1

NR - Not Recorded
<0.1 = 0.0999

Table B-8: Mean Seasonal Manganese (Mn) Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	0.07	0.02	0.26	NR
2	0.09	0.03	0.22	0.02
3	0.05	0.03	NR	0.02
4	0.10	0.03	0.20	0.02
5	0.05	0.02	NR	0.01
6	0.04	0.03	NR	0.02
7	0.04	0.03	NR	0.02
8	0.04	0.03	NR	0.03
9	0.06	0.02	0.19	0.05
10	0.04	0.02	NR	0.02
11	0.04	0.01	0.18	0.03
12	0.03	0.03	NR	0.02
13	0.03	0.02	NR	0.02
14	0.16	0.03	NR	0.02
15	0.03	0.03	NR	0.02
16	0.14	0.03	NR	NR
Seasonal Mean	0.06	0.02	0.21	0.02

NR - Not Recorded

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Table C-1	Mean Seasonal Total Coliforms Densities (orgs/100 mL) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).
Table C-2	Mean Seasonal Fecal Coliform Density (orgs/100 mL) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).
Table C-3	Mean Seasonal Fecal Streptococci Density (orgs/100 mL) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Table C-1: Mean Seasonal Total Coliforms Densities (orgs/100 mL) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	57	200	115	NR
2	306	204	357	<2
3	975	60	50	5
4	675	130	<10	3
5	485	130	67	2
6	769	60	17	<2
7	450	140	17	<2
8	380	360	10	<2
9	350	80	23	<2
10	694	27	120	2
11	569	87	<10	3
12	306	53	<10	<2
13	350	160	<10	2
14	375	340	33	6
15	194	240	<10	2
16	913	633	NR	NR
Seasonal Mean	490	182	57	3

NR - Not Recorded

Table C-2: Mean Seasonal Fecal Coliform Density (orgs/100 mL) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	<10	4	<2	NR
2	<10	1	<2	<2
3	<10	1	<2	2
4	<10	1	<2	<2
5	<10	33	<2	<2
6	<10	3	<2	<2
7	<10	1	<2	<2
8	<10	1	<2	<2
9	<10	<2	<2	<2
10	<10	1	<2	<2
11	<10	2	<2	<2
12	<10	3	4	<2
13	<10	<1	<2	<2
14	<10	<1	<2	2
15	<10	<1	<2	<2
16	70	2	NR	NR
Seasonal Mean	14	4	2	<2

NR - Not Recorded

Table C-3: Mean Seasonal Fecal Streptococci Density (orgs/100 mL) at Sampling Stations on Wàkaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	<10	4	4	NR
2	<10	1	<2	5
3	<10	<2	3	4
4	<10	1	<2	3
5	<10	1	<2	2
6	<10	2	<2	3
7	<10	1	<2	7
8	<10	2	<2	<2
9	<10	1	<2	<2
10	<10	1	<2	12
11	<10	<1	<2	3
12	<10	<1	15	11
13	<10	<1	<2	6
14	<10	<1	<2	3
15	<10	<1	<2	4
16	187	3	NR	NR
Seasonal Mean	21	2	3	5

NR - Not Recorded

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Table D-1 Mean Seasonal Total Phosphorus Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Table D-2 Mean Seasonal Total Kjeldahl Nitrogen Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Table D-3 Mean Seasonal Ammonia Nitrogen Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Table D-4 Mean Seasonal Nitrate-Nitrite Nitrogen Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Table D-5 Mean Seasonal Chlorphyll "a" Concentration (ug/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Table D-6 Mean Seasonal and Annual Chlorophyll "a" Concentration (ug/L) at Various Locations Along the Length Axis of Wakaw Lake (August, 1979-June, 1980).

Table D-7 Mean Seasonal Secchi Transparency (metres) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Table D-1: Mean Seasonal Total Phosphorus Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	0.04	0.05	0.07	NR
2	0.04	0.04	0.07	0.05
3	0.04	0.05	0.04	0.06
4	0.05	0.05	0.05	0.06
5	0.05	0.04	0.07	0.05
6	0.04	0.06	0.05	0.05
7	0.04	0.05	0.06	0.06
8	0.04	0.03	0.04	0.06
9	0.05	0.04	0.03	0.06
10	0.06	0.04	0.03	0.05
11	0.04	0.06	0.04	0.05
12	0.04	0.03	0.04	0.05
13	0.04	0.03	0.04	0.05
14	0.04	0.04	0.05	0.05
15	0.04	0.04	0.05	0.05
16	0.04	0.05	NR	NR
Seasonal Mean	0.04	0.04	0.05	0.05

NR - Not Recorded

Table D-2: Mean Seasonal Total Kjeldahl Nitrogen Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	1.4	1.4	3.2	NR
2	1.3	1.3	2.6	1.5
3	1.2	1.3	2.1	1.5
4	1.3	1.4	2.4	1.4
5	1.3	1.4	3.1	1.4
6	1.4	1.3	2.2	1.5
7	1.3	1.4	3.1	1.4
8	1.4	1.3	2.5	1.3
9	1.3	1.4	1.7	1.5
10	1.4	1.3	1.7	1.3
11	1.3	1.3	1.6	1.5
12	1.4	1.2	1.5	1.5
13	1.3	1.3	1.5	1.4
14	1.4	1.2	2.3	1.5
15	1.4	1.2	1.6	1.5
16	2.1	1.4	NR	NR
Seasonal ($\bar{x}$ ± SE)	1.32 ± 0.08	1.32 ± 0.02	2.21 ± 0.16	1.35 ± 0.17
Annual ($\bar{x}$ ± SE)	1.50 ± 0.08			

Table D-3: Mean Seasonal Ammonia Nitrogen Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	0.02	0.02	0.56	NR
2	0.01	0.01	0.40	0.04
3	0.01	0.03	0.33	0.02
4	0.07	0.02	0.46	0.03
5	0.02	0.06	0.86	0.02
6	0.01	0.01	0.64	0.07
7	0.01	0.03	0.66	0.03
8	0.02	0.01	0.35	0.02
9	0.04	<0.01	0.28	0.03
10	0.04	<0.01	0.31	0.03
11	0.05	<0.01	0.22	0.06
12	0.04	0.01	0.19	0.03
13	0.05	<0.01	0.17	0.02
14	0.05	<0.01	0.35	0.02
15	0.19	<0.01	0.17	0.02
16	0.69	0.11	NR	NR
Seasonal ($\bar{x}$ + SE)	0.08 ± 0.04	0.02 ± 0.01	0.40 ± 0.05	0.03 ± 0.00
Annual ($\bar{x}$ ± SE)	0.13 ± 0.09			

Table D-4: Mean Seasonal Nitrate-Nitrite Nitrogen Concentration (mg/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	<0.03	<0.03	<0.03	NR
2	<0.03	<0.03	<0.03	<0.03
3	<0.03	<0.03	<0.03	<0.03
4	0.04	<0.03	<0.03	<0.03
5	0.04	<0.03	<0.03	<0.03
6	<0.03	<0.03	<0.03	<0.03
7	<0.03	<0.03	<0.03	<0.03
8	0.05	<0.03	<0.03	<0.03
9	<0.03	<0.03	<0.03	<0.03
10	<0.03	<0.03	<0.03	<0.03
11	0.04	<0.03	<0.03	<0.03
12	<0.03	<0.03	<0.03	<0.03
13	<0.03	0.02	<0.03	<0.03
14	<0.03	<0.03	<0.03	<0.03
15	<0.03	<0.03	<0.03	<0.03
16	0.08	<0.03	NR	NR
Seasonal ($\bar{x}$ + SE)	0.04 $\pm$ 0.003	<0.03 $\pm$ 0.00	<0.03 $\pm$ 0.00	<0.03 $\pm$ 0.00
Annual ($\bar{x}$ $\pm$ SE)	0.03 $\pm$ 0.003			

Table D-5: Mean Seasonal Chlorophyll "a" Concentration (ug/L) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	3	7	8	NR
2	4	5	11	9
3	7	<1	3	10
4	10	4	2	15
5	8	6	4	12
6	12	10	<1	17
7	8	9	<1	17
8	7	9	<1	18
9	13	8	<1	15
10	8	10	<1	17
11	7	7	<1	16
12	7	7	<1	6
13	11	6	<1	7
14	3	<1	<1	9
15	1	<1	<1	8
16	10	12	NR	NR
Seasonal Mean ($\bar{x}$ + SE)	7.4 $\pm$ 1.7	6.1 $\pm$ 0.8	2.5 $\pm$ 0.8	12.6 $\pm$ 1.1
Annual Mean ($\bar{x}$ $\pm$ SE)	7.2 $\pm$ 2.1			

<1 - 0.999
NR - Not Recorded

Table D-6: Mean Seasonal and Annual Chlorophyll "a" Concentration (ug/L) at Various Locations Along the Length Axis of Wakaw Lake (August, 1979-June, 1980).

Spatial Location (Station No.)	Mean Seasonal Chlorophyll "a" Concentration				Annual Mean Concentration
	1979		1980		
	August	October	February	June	
1	3	7	8	NR	6.0 ± 1.5
2, 3	6	3	7	10	6.5 ± 1.4
4	10	4	2	15	7.8 ± 2.9
5, 6, 7	9	8	2	15	8.5 ± 2.7
8, 9, 10	9	7	<1	17	8.5 ± 3.3
11	7	7	<1	16	7.8 ± 3.1
12, 13, 14	7	5	<1	7	5.0 ± 1.4
15	1	<1	<1	9	2.8 ± 1.8

<1 - Value as recorded by ESQUADAT = 0.999
NR - Not Recorded

Table D-7: Mean Seasonal Secchi Transparency (metres) at Sampling Stations on Wakaw Lake (August, 1979-June, 1980).

Sampling Station No.	August 20-22/79	October 15-17/79	February 25-27/80	June 02-04/80
1	*	*	NR	NR
2	*	*	NR	*
3	*	*	NR	*
4	1.8	1.9	NR	1.5
5	*	2.0	NR	*
6	1.8	2.0	NR	1.6
7	2.0	2.0	NR	1.5
8	*	*	NR	*
9	2.0	2.1	NR	1.5
10	*	*	NR	*
11	1.7	2.2	NR	1.5
12	NR	*	NR	1.9
13	2.0	2.0	NR	*
14	*	*	NR	*
15	NR	*	NR	*
16	NR	NR	NR	NR
Seasonal Mean ($\bar{x}$ + SE)	1.9 ± 0.1	2.0 ± 0.0	NR	1.6 ± 0.1
Overall Mean	1.8 ± 0.1			

* - Secchi transparency not determined due to shallow water.
NR - February, 1980 survey Secchi transparency not recorded due to ice cover on lake.

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Table E-1 Total Phytoplankton Cell Volume (u^3/L) Observed at Wakaw Lake (All stations combined) 1979-80.

Table E-2 Total Phytoplankton Densities (cells/L) Observed at Wakaw Lake (All stations combined) 1979-80.

Table E-1: Total Phytoplankton Cell Volume (u^3/L) Observed at Wakaw Lake (All stations combined) 1979-80.

Phylum	Total Cell Volume (u^3/L)			
	August 20/79	Feb. 25-27/80*	June 3/80	Total
Chlorophyta	1.1×10^9	6.3×10^8	1.7×10^9	3.4×10^9
Chrysophyta	4.5×10^9	3.9×10^9	27.3×10^9	35.7×10^9
Cyanophyta	231.0×10^9	13.1×10^9	20.4×10^9	264.0×10^9
Euglenophyta	NF	5.8×10^7	7.0×10^6	6.5×10^7
Pyrrhophyta	9.7×10^9	1.3×10^9	2.9×10^9	13.9×10^9
Total	246.3×10^9	19.0×10^9	52.3×10^9	317.0×10^9

* - Results for February expressed as means of values recorded on the three sampling dates.
NF - Not Found.

Table E-2: Total Phytoplankton Cell and Colony Densities (cells/L) Observed at Wakaw Lake (All stations combined) 1979-80.

Phylum	Total Cell Density (No./L) August 20/79	Feb. 25-27/80*	June 3/80	Total
Chlorophyta	4.4×10^6	8.9×10^6	2.0×10^7	3.3×10^7
Chrysophyta	38.8×10^6	7.9×10^6	25.8×10^7	37.6×10^7
Cyanophyta	7.4×10^6	19.6×10^6	2.2×10^7	4.9×10^7
Euglenophyta	NF	4.7×10^4	3.4×10^3	5.0×10^4
Pyrrhophyta	6.6×10^6	0.9×10^6	7.9×10^6	1.5×10^7
Total	57.2×10^6	37.3×10^6	30.8×10^7	47.3×10^7

* - Results for February expressed as means of values recorded on the three sampling dates.
NF - Not Found.